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# ENGINEERING DRAWING

# ENGINEERING DRAWING

## PRACTICE AND THEORY

*By*

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# PREFACE

This work is intended to meet the needs of engineering students and draftsmen for a textbook which will represent the fundamental principles of engineering drawing in a direct, practical manner. The subject is presented according to the author's conception of good practice as followed by the engineering profession. It is not meant, however, to be a handbook on drawing.

In collecting the material for this text, it was the author's intention to present the fundamental principles of the different phases of engineering drawing such as machine drawing, structural drafting (including architectural drawing), topographic drafting (including mining problems), etc. The theory of drawing (descriptive geometry) is introduced only as a means of presenting the practical side of drafting. Emphasis is, therefore, placed on current drafting-room practice. Heretofore, too much emphasis has been placed on "theoretical projections" (or geometrical callisthenics). Such practice tends to take the student's mind off the making of the drawing, the conventions, and idioms, and causes him to lose sight of the application of the theory.

When the orthodox method of presenting the subject of drawing is employed in engineering colleges, two formal courses are given: (1) Engineering Drawing and (2) Descriptive Geometry. The former represents "practice"; the latter presents the "theory." In this work the two are given simultaneously. The theory is first studied, and the application is then worked out. By so presenting the subject, the writer has been able to eliminate much duplication of classroom work. The student can thereby effect a considerable saving in time which will enable him to cover more material each term. Some of the more common duplications are: plane curves, orthographic drawings (principal views), auxiliary views, revolutions, true lengths, intersections, developments, and pictorials. Also, two different textbooks by different authors are used, which means the student must adjust himself to two different "methods of presentation", and two different "outlines of nomenclature", and must cover much material twice. Usually the transition period from "Engineering Drawing" to "Descriptive Geometry" is a severe jolt to the student. The author has found, after many years of pioneering in the method of presentation herein adopted, that one text on the subject of engineering drawing, and the presenting of "practice" and "theory" simultaneously, induce greater interest in the class, and result in fewer "flunks."

The "old-time engineer" will usually say: "Why teach 'descrip.'? Where do you use it? I have never had an occasion to apply it." His course in "descrip." consisted of theoretical exercises in geometry projected in all four of the dihedral angles, especially the first angle. (In practice, third-angle projection is used entirely.) When he had a drawing to make, he had to work out his own geometrical application and called it "just common-sense drawing" for he failed to recognize the descriptive geometry and its application which he had so laboriously studied in college.

Sincere appreciation is expressed for the valuable assistance of J. Vernon Otter in the preparation of drawings and for helpful criticisms during the preparation of the manuscript. The author is likewise indebted to Allen S. Janssen for proofreading the text matter, for valuable criticisms of the material, and for assisting in the preparation of drawings.

The author wishes also to express his appreciation to several commercial and industrial companies for permission to use drawings and photographs which have added greatly to the value of this work. Acknowledgments have been made in the body of the text.

Corrections, suggestions, and other criticisms from those using this material will be welcomed.

Isaac Newton Carter

Moscow, Idaho
June, 1936

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# CHAPTER I

## INTRODUCTORY

1-I. Engineering Drawing is the graphical language used by engineers and others of the technical professions to express their creative ideas. Its function is to carry information to be used in the design, construction, operation, and maintenance of engineering works, projects, and structures.

2-I. In writing this text the author has endeavored to present the subject according to his conception of good practice as followed by the engineering profession. The fundamental principles of engineering drawing are given in a direct, practical manner after the theory has been presented as a basis upon which to build the practical application.

The student should first visualize the object as it would appear in space. He should then draw what he sees when standing: (1) in front; (2) to the side; (3) above the object; or (4) in auxiliary position.

In addition to the training received in making engineering drawings, the student should be taught the reading and interpretation of drawings, the conventions used in executing drawings, drafting-room practices, and should be given a great deal of practice in lettering.

3-I. The Fundamentals of Drawing are few and not difficult to understand, but proficiency requires constant study, much practice, and a great deal of patience. The governing factors in executing a drawing are (a) accuracy, (b) speed, (c) neatness, and (d) style.

(a) In the profession accuracy is the keynote to success. The student should be ever on guard against making errors and use every possible check to assure accuracy. He should not expect that mistakes will never appear in his work. He should realize, however, that a higher degree of accuracy cannot be obtained than the accuracy of the data available; nevertheless, he should try to make as few errors as possible. If one never makes a mistake, it is very likely because one has never had the opportunity to attempt the worth-while things. When errors are made, therefore, one should be eager to correct them. An engineer should always profit by personal experiences (and by the experiences of others), so that the same or similar error shall not be repeated. It is customary in practical engineering to check all drawings and designs. The student draftsman should likewise have his drawings checked before inking them.

(b) Speed is one of the essential elements in engineering. It is to be ever encouraged. In practice one is often obliged to work under pressure at high speed. The habit of speed should be acquired now, so that from day to day one will be able to turn out a greater quantity of work with less labor. In this day of competition a slow draftsman cannot keep his place in a drafting room.

(c) Too much emphasis cannot be placed on the neatness and the general appearance of a drawing. Poor arrangement, improper weights of lines, bad judgment in dimensioning, and poor lettering will ruin the usefulness of a drawing in which the mechanical work has been carefully done. A piece of work that does not show careful construction, good lettering, and proper judgment in arrangement will not inspire confidence. The student should strive to attain the artist's touch, thereby making his work attractive. A drawing should be kept clean at all times.

(d) Engineering Drawing is a distinct language within itself. It is a graphical language. There is a "style" in drawing just as there is a "style" in literature. Style in drawing is indicated by the ease and accuracy with which a drawing may be read. A good drawing will stand out, while other drawings containing all the necessary information are difficult to decipher. The number of principal views, selection and placement of principal views, proper use of sectional and auxiliary views, elimination of ambiguous and unnecessary parts of a drawing, choice and manner of placing dimensions, good lettering, proper use of line shading, idioms or violation of theory, and contrast of lines are all elements concerned in the "style."

No one of these elements, so essential in drawing, should ever be neglected. The student draftsman should strive, therefore, to secure a harmonious blending of these few drawing fundamentals, and thereby obtain the best results.

4-I. Plate Layout. The exercises are listed at the end of each chapter. They are divided into characteristic groups and are numbered consecutively, beginning with 1, in each group. Exercise 3 in Group 2 of Chapter IV may be referred to as 3-2-IV. Likewise, articles and figures are numbered consecutively, beginning with 1, in each chapter. Thus, article 4-I, this article, is the fourth in Chapter I, and Figure 2-I is the second figure in Chapter I.

The lettering plate layout of Figure 1-I is a convenient arrangement for the lettering exercises of Chapter II. Detailed dimensions are given, and the order of procedure is illustrated in the layout.

Four drawing plate layouts are illustrated in Figure 2-I, with detailed dimensions, and two title forms. The different plate sizes illustrated are well suited to the exercises of this text. Layout (C) is intended for Homework exercises; the other layouts are more commonly used for Drafting-room Work.

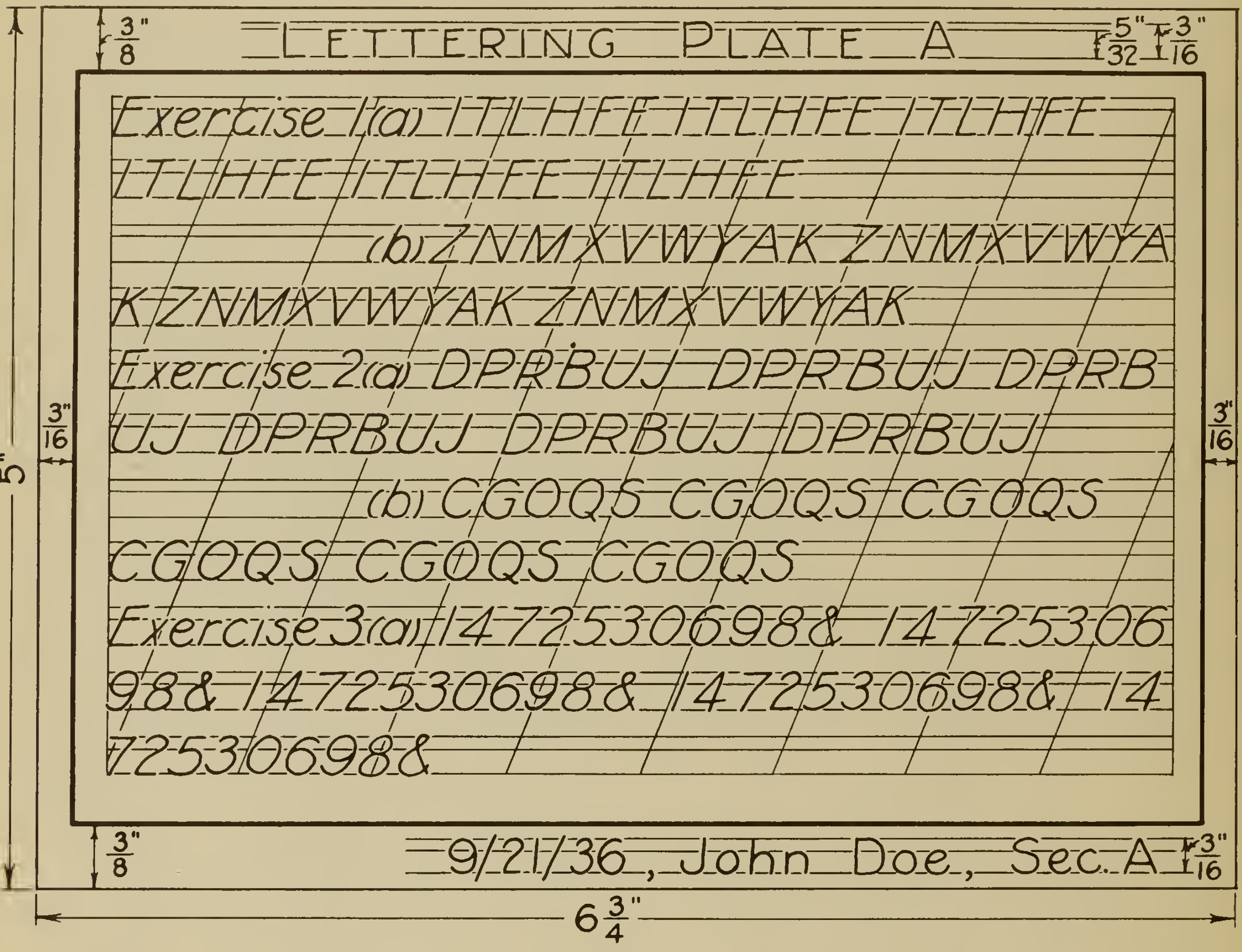
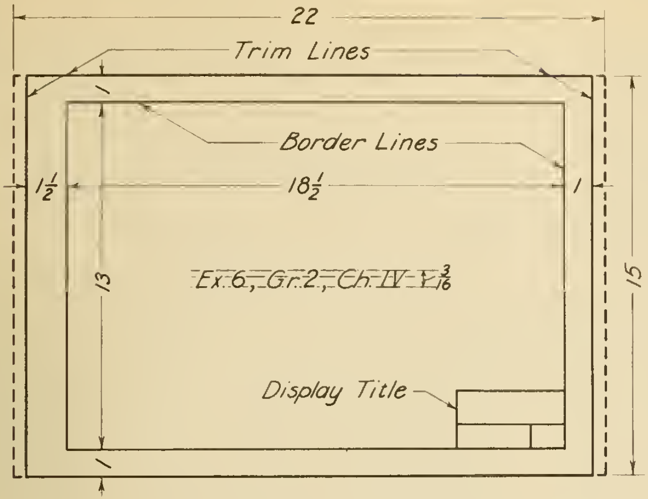
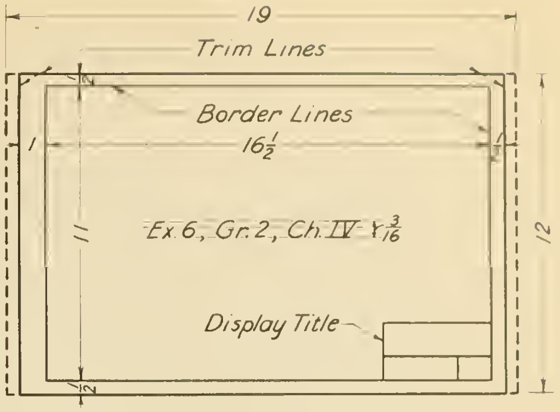


Figure 1-I. Lettering Plate Layout

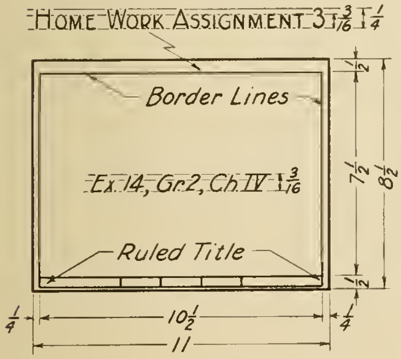


(A) FINISHED SIZE 15×21

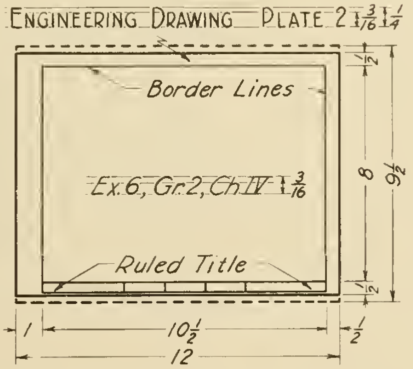


(B) FINISHED SIZE 12×18

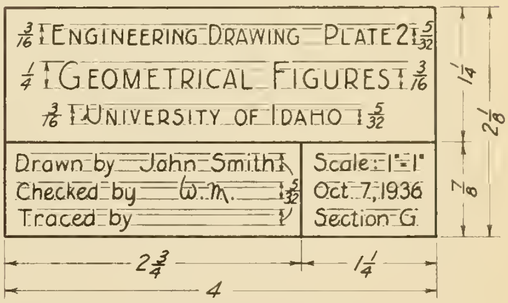
Note: The lettering for Headings and Titles is vertical.



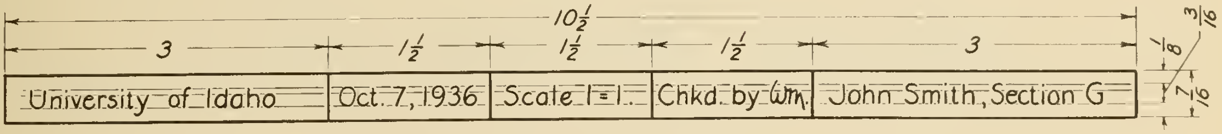
(C) FINISHED SIZE 8½×11



(D) FINISHED SIZE 9×12


3/16 ENGINEERING DRAWING PLATE 2 5/32
¼ GEOMETRICAL FIGURES 3/16
3/16 UNIVERSITY OF IDAHO 5/32
Drawn by John Smith
Checked by W.M. 5/32
Traced by
Scale 1"=1"
Oct. 7, 1936
Section G
1¼
2⅛
⅞
2¾
1¼
4

DISPLAY TITLE FORM



RULED TITLE FORM

Figure 2-I. Drawing Plate Layout

# CHAPTER II

## LETTERING

1-II. The engineering student should begin free-hand lettering as his first exercise in drawing and should continue the practice of lettering as long as he is making a study of the science of drawing. No one phase of engineering drawing is as important as the subject of lettering. The usefulness of a drawing may be ruined by careless and illegible lettering. Such negligence fails to inspire confidence in the correctness of the drawing and often leads to errors in reading.

According to the manner of execution, there are two classifications generally made, (1) single stroke or free-hand letters and, (2) built-up or blocked-out letters.

The Gothic letter, most commonly used in engineering drawing, should be made as a single-stroke letter drawn free-hand. All others are blocked-out in outline, or built-up, by use of the straightedge and pencil--drawn in outline or skeleton--and then inked with a ruling pen and straightedge. The use of mechanical devices for making letters results in stiff, awkwardly shaped letters. Such devices are not desirable. Lettering is not printing. Printing is done in a print shop.

2-II. Some Common Styles of Letters. As already stated, the most common letter used in engineering drawing is the Gothic. It is drawn free-hand and is made by a series of single strokes of the pencil or pen. The Gothic letter is made either vertical or inclined. The inclined letter is more commonly used.

Other styles of letters in common use by engineers are commercial block or commercial Gothic, modern Roman, railroad block, spurred Gothic, and a few others. See Figures 14-II to 19-II.

3-II. Horizontal and Vertical Proportions of Letters. There is no set rule to govern the width or height of a letter. The height is fixed and is usually constant for a particular line or paragraph, and then the widths of the normal letters are arbitrarily chosen. See Figure 1-II, inclined, single-stroke Gothic letters.

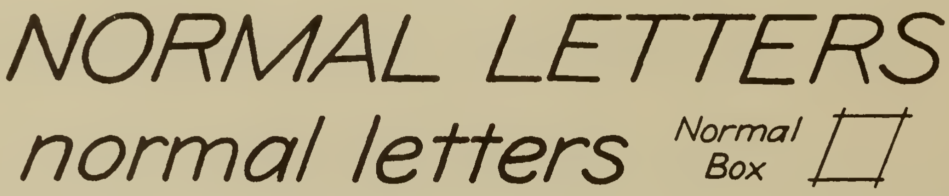


Figure 1-II

It often becomes necessary to crowd a considerable number of words into a short line. When this is done the lettering is said to be compressed, Figure 2-II.

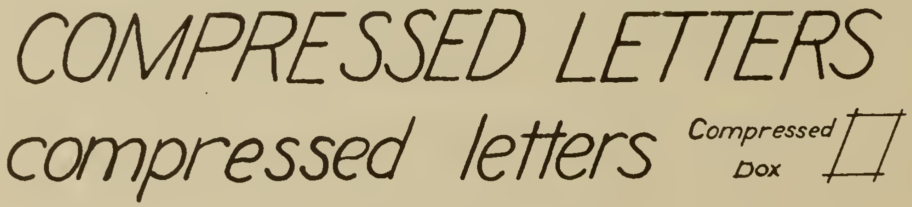


Figure 2-II

If only a few words are used, and it is thought necessary to fill the entire line, the letters are widened--the spacing between letters remaining the same--until the line is filled or nearly filled. When this is done, the lettering is said to be extended, Figure 3-II on the following page.

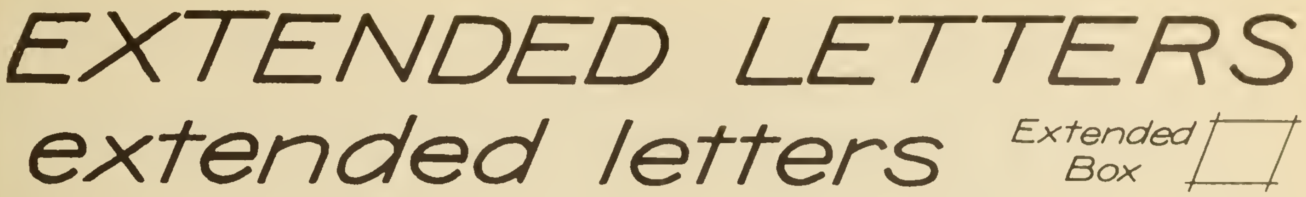


Figure 3-II

It might be said, for most work, that the more common letters, such as D, H, N, S, T, X, and the like, are slightly taller than they are wide. But the ratio of the width to the height will depend upon the style of lettering to be used. It will be noticed that I is the narrowest letter, while W is the widest.

The widths of the stems of letters vary widely. The ratio of the width of the stem to the height of the normal letter will vary from 1/5 to 1/10, depending upon the style of lettering used. Letters with exceptionally slender stems are called lightface letters, while letters with very broad stems are called boldface or blackface letters.

In order to have a letter or numeral appear stable and not top-heavy, the horizontal division line, if there be one, should fall slightly above the center of the letter. A more general rule is to have the upper division of a letter appear smaller than the lower part. This is illustrated by the letters B E F H P R S X and the numerals 3 5 8 9. Exceptions to this rule are A K Y 4 6. The horizontal division lines of these characters fall below the center. Nevertheless, the upper divisions appear smaller than the lower division.

4-II. Single-Stroke Lettering. The term "single-stroke" does not mean that the entire letter is made by one continuous stroke of the pen. On the contrary, the letter is made up of a series of single strokes. In the composition of a letter each stroke has a definite order and direction which should be observed every time the letter is made. Before the hand can execute, the mind must conceive, and then there must be coordination between the mind and the muscles. Before a letter is begun, the mind must first have a perfect image of the letter, the number of strokes with which it is composed, the order in which each stroke comes, and the direction in which each stroke is made. Without first having this mental image and knowledge, the mind will fail to function smoothly while the composition is going on.

Guide lines should always be drawn lightly in pencil before lettering is begun, even though a single letter, numeral, or character is to be made. The letter is usually made with a soft pencil first and afterward inked over. An experienced draftsman, however, will do a great deal of his lettering directly in ink.

An F or H pencil is best for lettering. The pencil should be kept sharpened with a conical point. A light touch should be developed. There should never be enough weight put on the pencil to make creases in the paper. Too much pressure put on the pen will spread the nibs, causing uneven widths of the different strokes and resulting in a non-uniform letter. A pen should be chosen which will give the proper weight of line without spreading the nibs. The following pens constitute an evenly graded series in weight from heavy to light: (1) Ball point 516 F, (2) Hunt 67, (3) Gillott 404, (4) Gillott 303, (5) Gillott 170.

The arm should be extended in front of the body and kept that way. The pen or pencil should be held lightly as in penmanship practice. If the weight of the body is to be rested on either arm, let it fall on the arm not in motion. Weight on the arm and a tight grip on the pen or pencil cause tense muscles, which will produce rapid tiring of the arm and fingers and result in jerky strokes. The elbow should rest on the table so that the whole arm will have a support. Horizontal strokes should be made from left to right. Vertical strokes should be drawn from top to bottom.

5-II. Single-Stroke Inclined Letters and Numerals. By far the most common style of lettering used in engineering is the single-stroke, inclined. It is often called the Rienhardt or Engineering-News lettering. It is composed of commercial Gothic letters with an inclination of approximately 22 1/2 degrees to the right of the vertical. The slope would be equivalent to 2 units horizontal to 5 vertical, i.e., the slope of the hypotenuse of a right-angle triangle when the horizontal leg is 2 units in length and the vertical leg is 5 units in length, Figure 10-II.

This style of lettering lends itself admirably to rapid execution and at the same time presents a neat appearance. The student should remember (1) to letter rapidly and neatly, following the order and direction of the strokes as indicated; (2) to use guide lines; (3) to keep uniform slopes; (4) to keep the spacing between letters close and uniform; (5) to have the letters full and well shaped with even, uniform strokes.

The letters and numerals are divided into characteristic groups in the following order: (1) Capitals, (2) Numerals, (3) Lower-case letters. The lower-case letter is the small letter. In lettering practice this group series should be adhered to--together with the five precautions given above--until the student has formed a mental image of the letters, the order in which the strokes come, and the direction in which they are made.

6-II. Capitals. The letters composed of horizontal and inclined strokes are taken in the first characteristic group, as is illustrated in Figure 4-II. The student should carefully observe the rule of stability, i.e., keep the upper division of the letter smaller than the lower division.

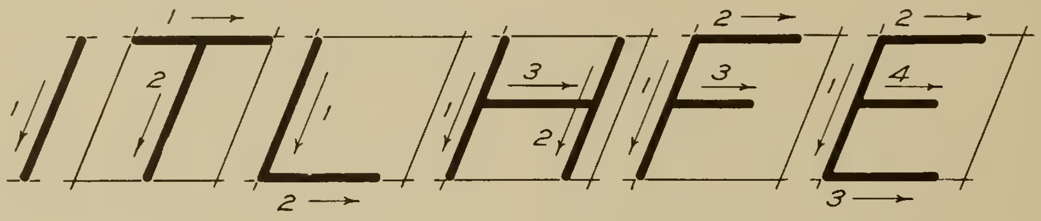


Figure 4-II

The second characteristic group is composed of letters formed by inclined, horizontal, and cross strokes, as indicated in Figure 5-II. Extreme care should be exercised in drawing the inclined lines of A, V, and W. The lines sloping from left to right are more nearly vertical.

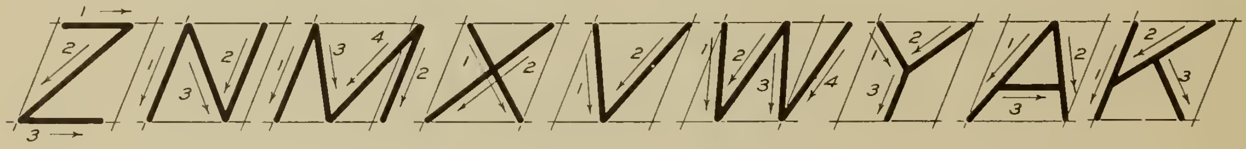


Figure 5-II

Figure 6-II illustrates the third characteristic group, which is composed of horizontal, inclined, and curved lines. Extreme care should be exercised in connecting the curves and tangents in order to make smooth connections in joining the lines.

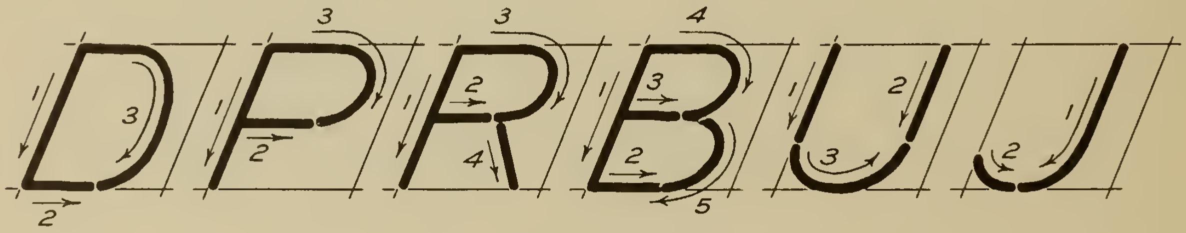


Figure 6-II

With the exception of G, which contains two short tangent lines, the characteristic group shown in Figure 7-II, on the following page, consists of letters made up of curved lines. These letters should be studied closely, and extreme care should be exercised in observing the rules and precautions above.

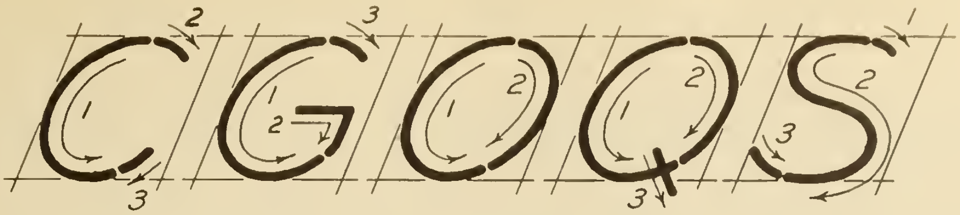


Figure 7-II

7-II. Numerals. A full set of the inclined numerals, including the character "&", are listed in Figure 8-II. The straight line characters are listed first, with the more complicated ones at the end. The 0, 6, and 9 are narrower than the letter O. The stability rule should be very carefully observed in the case of 8, 3, 6, 9, 4, and 5.

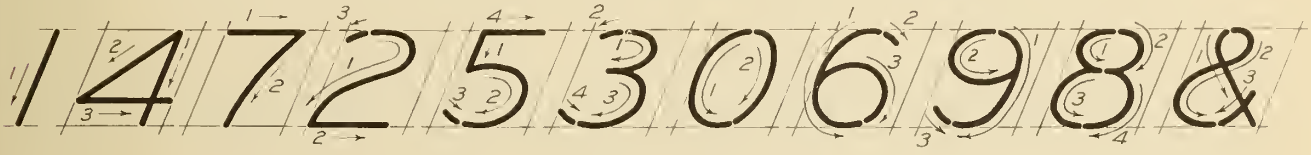


Figure 8-II

The beginner, and even the more experienced draftsman, so often makes fractions which are difficult if not impossible to read, by crowding the entire fraction in between the cap line and the base line and by permitting the numerals in the numerator and denominator to touch the division line of the fraction. The division line should always be horizontal. These crowded conditions cause blurring and blotting, which tend to make the fraction illegible. See Figure 9-II. It has been stated that the numerals are the same height as the capitals, but the fractions extend above the cap line and drop below the base line, as illustrated. It should be noticed that the waist line, used for lower-case letters, is two-thirds the distance from the base line to the cap line measured above the base line. It is the distance 2/3 H, Figure 9-II. The peak line is 1/3 H above the cap line, while the drop line is 1/3 H below the base line.

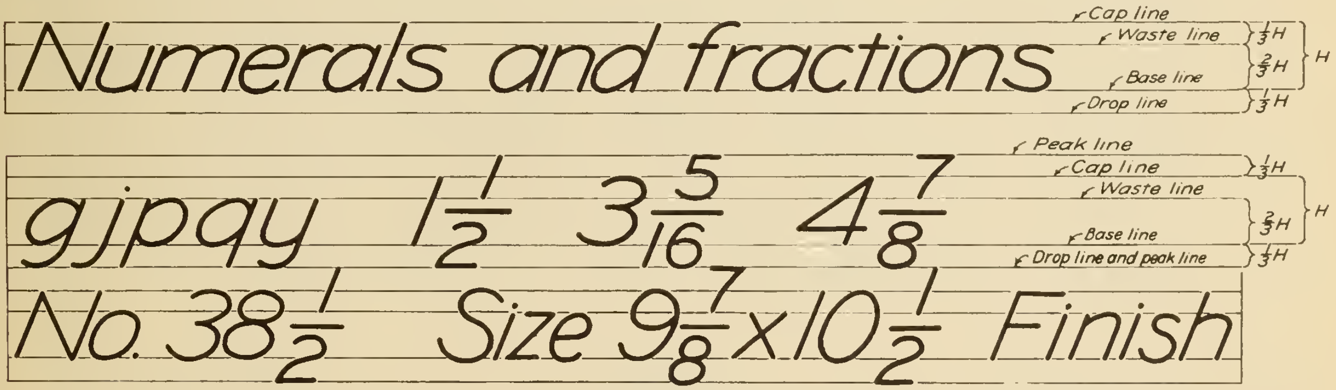


Figure 9-II

8-II. Lower-case Letters. As stated, lower case refers to the small letters in the alphabet. The manner of constructing the guide lines is illustrated in Figure 9-II. The base and cap lines should be drawn each time. The waist line should always be constructed when lower-case letters are used. The entire inclined alphabet and numerals are illustrated in Figure 10-II on page 8. It will be noticed that such letters as b, f, h, k,

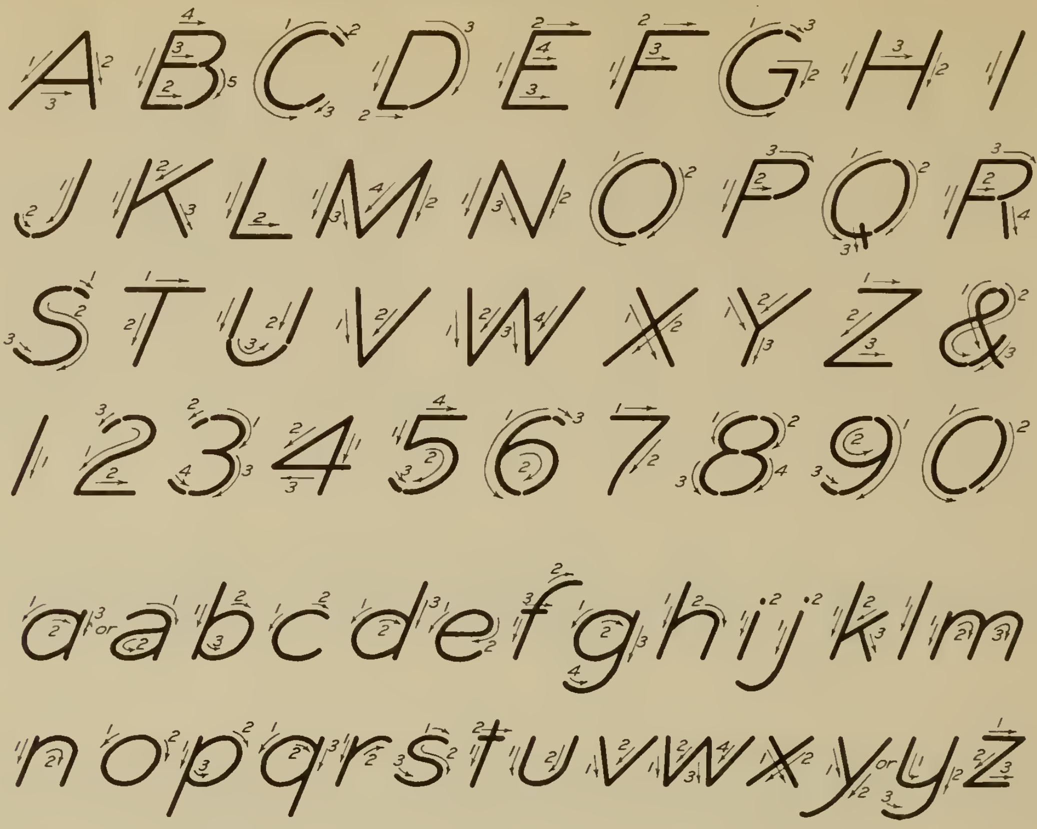


Figure 10-II. Single-Stroke Inclined Caps and Lower Case

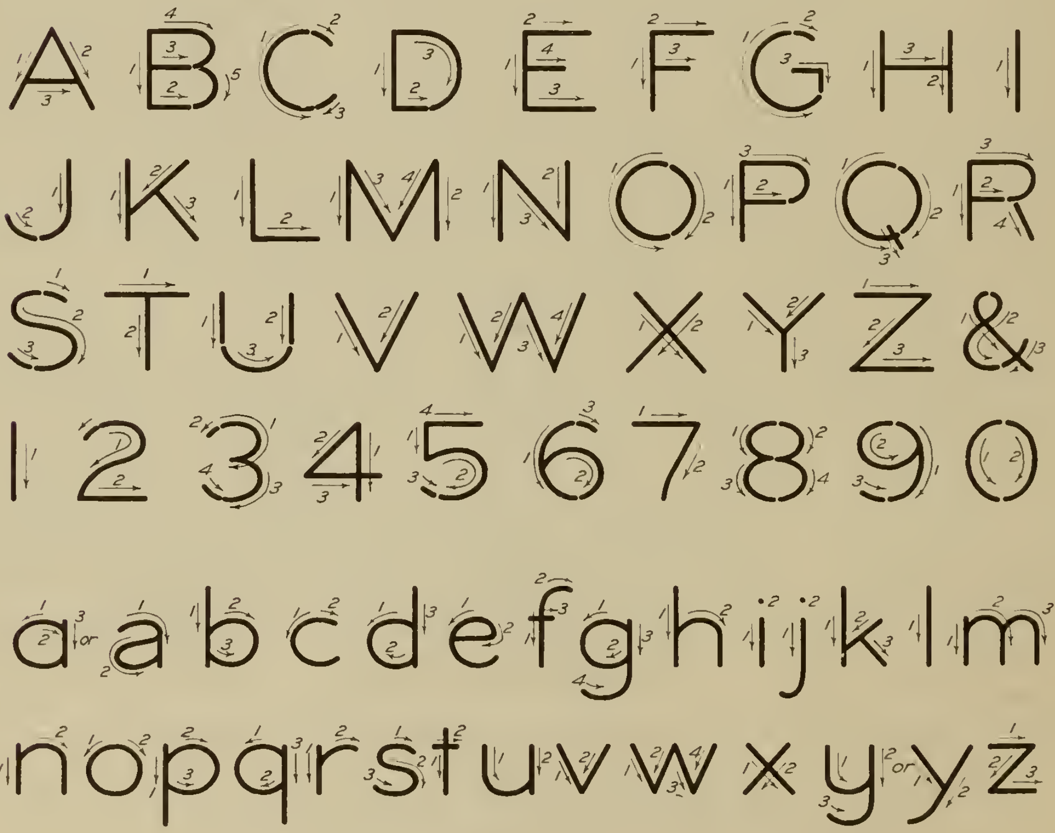


Figure 11-II. Single-Stroke Vertical Caps and Lower Case

and l extend from the base to the cap line. The letters a, c, m, s, etc., extend only from the base line to the waist line, while g, p, and y extend from the waist line down to the drop line. The order and direction of the strokes composing each letter and numeral are given. The illustrations should be followed.

9-II. Single-Stroke Vertical Letters and Numerals. The vertical single-stroke style of lettering has a wide use among engineers. It is probably second in use to the inclined single-stroke lettering. Titles, headings, and notes which refer to the entire plate or drawing are often put in vertical letters, while inclined letters are used for the individual parts or for detail drawings. Machine drawing employs vertical letters. The order and direction of strokes are as shown in Figure 11-II on the preceding page. Practice exercises should be carried out as before, but reference should be made to Figure 11-II for the strokes and shape of each letter and each numeral.

10-II. Composition. After the shape, slope, and stroke of the individual letter have been mastered, the composition of letters should be studied. Composition has to do with the selection of the style of letters (when there is a choice), letter sizes, and spacing between letters and between words. A great deal of care should be given to spacing.

The spacing between letters in a word should be adjusted so that the white space, or apparent space, between the various letters will seem to be equal. Take, for instance, LATAH COUNTY. The white space between the various letters in the first word should be adjusted to match the largest amount of white space between any two letters, i.e., L and A, in this case. In COUNTY, the spacing in the word should be adjusted to match the space between T and Y. By this scheme the spacing in each word will appear to be balanced and uniform. The spacing between words in a line may vary from one to one and one-half times the height of the letters. The distance between the different lines of letters in a paragraph should be uniform but may vary from one-half to one times the height of the letter.

The size of the letters to be used is often fixed by office rules. For ordinary-sized plates, 3/16-inch letters are commonly used in headings and titles, both for the entire plate and for the detail drawings. If this size is used, then all the rest of the lettering on the plate should be 1/8-inch. If there is a large heading across the entire plate, an extended line of vertical letters of large and small caps will look attractive. For the average-sized plate 1/4-inch letters will do. The small caps should be about 4/5 the height of the large caps.

After the size and style of the letter have been decided upon, a pen should be chosen which will give the proper weight to the letter stem.

If notes are placed on a drawing, each paragraph should not be indented. The two edges--especially the left--should be kept vertical.

11-II. Title. The title is a very necessary part of the drawing. It furnishes the record and descriptive data concerning the subject matter. There are two forms in common use, i.e., display and ruled titles. The scheme of the display title follows very closely the principles employed in laying out a display advertisement. The feature of the drawing is displayed in the principal lines of the title, while other parts less important are suppressed by using lettering that is smaller than the display lines and not so prominent in style. A ruled title is one which occupies a space that has been ruled off especially for it with ruled subdivisions for all the data. The ruling is often printed on the sheet. This form of title practically, if not entirely, precludes the display feature. Practice seems to tend more to the ruled title. See Figures 12-II, 13-II, 3-XIV, and 19-XIV.

The display title should be symmetrical

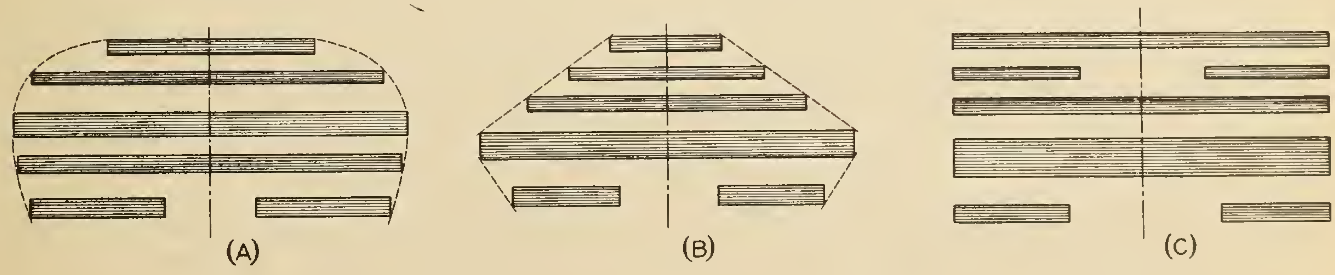


Figure 12-II. Blocking Out Display Titles

about a vertical center line, and the outline should conform to an oval section, preferably with the fatter or fuller part at the bottom. It will be noticed in Figure 12-II that the center of area in each instance has been kept below the horizontal center line. Title (C) is rather severe and not so artistically arranged as (A) and (B). This cannot be avoided on all occasions.

12-II. Letter Styles Commonly Used in Engineering Drawing. In addition to the single-stroke or Gothic letters so commonly used in engineering, other styles are employed, especially when the larger-sized letters are used. In Figures 14-II to 18-II inclusive the commercial block, spurred block, railroad block, modern Roman, and speed-ball letters are illustrated.

After a drawing has been completed, a border should be drawn, sufficiently heavy to balance the matter included in the drawing. A plain border is often used but occasionally a more artistic design is wanted. See Figure 19-II.

## EXERCISES

13-II. To become proficient in lettering, the student should practice often but not too long at one time. In the beginning he should:

1. Always have a copy of the letters before him while practicing.
2. Visualize the shape before starting to draw the letter.
3. Follow the order and the direction of strokes as given in the text.

For the following exercises the student ought to secure a good bond paper, preferably a ledger bond, and rule the paper as directed. He should keep his pencil well sharpened with a conical point, and make light letters.

## Group 1-II. Letter Forms

In this group the individual letter is studied for form and slope and is then reproduced on a lettering plate. In order to obtain the proper lettering form, the student should use (1) the correct number of strokes, (2) the order in which each stroke comes, and (3) the direction of stroke as outlined in the text. He should draw an occasional slope line, inclined or vertical, to aid him in obtaining the proper letter slope.

1. (a) Use 1/4-inch ruling. Reproduce the letters from Figure 4-II (page 6) with an F or an H pencil. Repeat the series six times, making a total of 36 letters.
   (b) Reproduce the letters from Figure 5-II (page 6) in pencil. Repeat the series four times, making a total of 36 letters.
2. (a) Use 1/4-inch ruling. Reproduce the letters from Figure 6-II (page 6) in pencil. Repeat the series six times, making a total of 36 letters.
   (b) Reproduce the letters from Figure 7-II (page 7) in pencil. Repeat the series seven times, making a total of 35 letters.
3. (a) Use 1/4-inch ruling. Reproduce in pencil the numerals and the character "&" of Figure 8-II (page 7). Repeat the series three times, making a total of 33 letters.
   (b) Draw the following fractions (see Figure 9-II, page 7 for a correct method of drawing fractions) in pencil: 3 1/4, 5 2/3, 6 7/8, and 9 3/4. Repeat the series ten times, making a total of 40 numerals with 40 fractions.
4. (a) Use 3/16-inch ruling. Using a lettering pencil, reproduce the letters of Figures 4-II and 5-II (page 6) in consecutive order, beginning at "I" and progressing through "K". Repeat the entire series five times, making a total of 75 letters.
   (b) Beginning with the first series of Exercise 4 (a) above, "I" to "K" inclusive, ink the penciled letters by carefully tracing them. Use a ball-point lettering pen and waterproof drawing ink. Ink only the first, third, and fifth series. Leave the second and fourth series in pencil.
5. (a) Use 3/16-inch ruling. Using a lettering pencil, reproduce in consecutive order the letters of Figures 6-II and 7-II (pages 6 and 7), beginning at "D" and progressing through "S". Repeat the entire series seven times, making a total of 77 letters.
   (b) Using a Hunt lettering pen, ink the first, third, fifth, and seventh series of Exercise 5 (a). Leave the second, fourth, and sixth series in pencil.
6. (a) Use 3/16-inch ruling. Reproduce in pencil: first, the numerals and character "&" of Figure 8-II(page 7); second, the following fractions: 3 1/4, 5 2/3, 6 7/8, 9 3/4. Repeat this procedure five times, making a total of 55 numerals and characters, and 20 numerals with 20 fractions.

(b) Using a Hunt lettering pen, ink the first, third, and fifth series of each group; i.e., first, start with the numeral "1" and end with the character "&"; second, start with the numeral-and-fraction "3 1/4" and end with the numeral-and-fraction "9 3/4." Leave the second and fourth series of each group in pencil.

7. (a) Use 1/8-inch ruling. Using a lettering pencil, reproduce in consecutive order the letters of Figures 4-II and 5-II (page 6), beginning at "I" and progressing through "K". Repeat the entire series five times, making a total of 75 letters.
   (b) Using a Gillott 303 pen, ink the first, third, and fifth series of Exercise 7 (a). Leave the second and fourth series in pencil.
8. (a) Use 1/8-inch ruling. Using a lettering pencil, reproduce in consecutive order the letters of Figures 6-II and 7-II (pages 6 and 7) beginning at "D" and progressing through "S". Repeat the entire series seven times, making a total of 77 letters.
   (b) Using a Gillott 303 pen, ink the first, third, fifth, and seventh series of Exercise 8 (a). Leave the second, fourth, and sixth series in pencil.
9. (a) Use 1/8-inch ruling. Reproduce in pencil: first, the numerals and character "&" Figure 8-II (page 7); second, the following fractions: 3 1/4, 5 2/3, 6 7/8, 9 3/4. Repeat this procedure five times, making a total of 55 numerals and characters, and 20 numerals with 20 fractions.
   (b) Using a Gillott 303 pen, ink the first, third, and fifth series of each group; i.e., first, start with the numeral "1" and end with the character "&"; second, start with the numeral-and-fraction "3 1/4" and end with the numeral-and-fraction "9 3/4." Leave the second and fourth series of each group in pencil.
10. (a) Use 3/16-inch ruling. Refer to Fig-10-II. Letter the entire alphabet in inclined capitals with a lettering pencil.
    (b) Using a Gillott 404 pen, ink the penciled letters of Exercise 10 (a).
    (c) Repeat Exercise 10 (a) above, but letter the alphabet in ink directly without the aid of the penciled lettering. Use a Gillott 404 pen.
11. (a) Use 3/16-inch ruling. Refer to Figure 10-II. Reproduce the entire alphabet in inclined lower-case letters with a lettering pencil.
    (b) Using a Gillott 404 pen, ink the penciled letters of Exercise 11 (a).
    (c) Repeat Exercise 11 (a), but letter the alphabet in ink directly without the aid of the penciled lettering. Use a Gillott 404 pen.
12. (a) Use 3/16-inch ruling. Refer to Figure 10-II. Reproduce the inclined numerals in pencil.
    (b) Using a Gillott 404 pen, ink the penciled numerals of Exercise 12 (a).
    (c) Repeat Exercise 12 (a), but letter the numerals in ink directly without the aid of the penciled lettering. Use a Gillott 404 pen.
13. (a) Use 3/16-inch ruling. Using a lettering pencil, reproduce Figure 11-II (capital letters, lower-case letters, and numerals) in the vertical style.
    (b) Using a Gillott 404 pen, ink the penciled letters and numerals of Exercise 13 (a).
    (c) Repeat Exercise 13 (a), but reproduce the letters and numerals in ink directly without the aid of the penciled lettering. Use a Gillott 404 pen.
14. (a) Use 1/8-inch ruling. Refer to Figure 11-II. Reproduce in pencil the entire set of numerals, including the character "&". Use vertical lettering. Repeat the series four times, making a total of 44 numerals and characters.
    (b) Using a Gillott 303 pen, ink the penciled numerals and characters of Exercise 14 (a).
    (c) Repeat Exercise 14 (a), but reproduce the numerals and characters in ink directly without the aid of the penciled lettering. Use a Gillott 303 pen.
15. (a) Use 1/8-inch ruling. Referring to Figure 11-II, reproduce in pencil the entire alphabet in vertical lower-case letters.
    (b) Using a Gillott 303 pen, ink the penciled letters of Exercise 15 (a).
    (c) Repeat Exercise 15 (a), but reproduce the letters in ink directly without the aid of the penciled lettering. Use a Gillott 303 pen.
16. (a) Use 1/8-inch ruling. Using a lettering pencil, reproduce Figure 10-II (capital letters, lower-case letters, and numerals) in the inclined style.
    (b) Using a Gillott 303 pen, ink the penciled letters and numerals of Exercise 16 (a).

(c) Repeat Exercise 16 (a), but reproduce the letters and numerals in ink directly without the aid of the penciled lettering. Use a Gillott 303 pen.

### Group 2-II. Composition in Lettering

The student should carefully letter the following exercises in composition, paying especial attention to the spacing between the letters of a word, the spacing between the words of a line, and the spacing between the lines in a paragraph. The letters in a word should be spaced uniformly close together. The spacing between the words in a line should be uniform and equal to the height of the capital. The spacing between the lines in a paragraph should be uniform and equal to the distance that the waist line is above the base line, as illustrated in Figure 9-II.

1. Use 3/16-inch ruling. Using the inclined style of lettering and a Gillott 303 pen, letter the following directly in ink: It is essential that a draftsman be able to do good lettering. An otherwise perfect drawing might be made illegible by improperly executed lettering. The division line of a fraction should be horizontal. Neither the numerator nor the denominator should touch the division line. Dimensions should never be crowded.
2. Repeat 1, but use the following copy: Note: Finish all moving parts. Allowable tolerance should not exceed plus or minus 0.003.

   The idioms of drawing, or violations of theory, should always be used when they tend to make the drawing easier and quicker to read.
3. Use 1/8-inch ruling. Using the inclined style of lettering and a Gillott 170 pen, letter the following directly in ink: Weights should not be laid on a straightedge to hold it in place. The T-square should not be used as a hammer. It should not be allowed to drop on the floor. It should not be used as a guide edge to cut paper. Always use the side of the straightedge farthest from you when drawing.
4. Repeat 3, but use the following copy: The pencil should not be sharpened over a drawing. Always keep the pencil well sharpened with a conical point. Never bear down on a pencil. Do not put either end of the pencil in the mouth. The scale should not be used as a ruler. Do not scrub inked lines when cleaning a drawing; it will take the life out of them.
5. Repeat 3, but use the following copy: Always keep a dust cloth and a blotter on the desk. Immediately brush off all eraser dust after an erasure has been made. Do not try to blot lines made with drawing ink as you would those made with fountain pen ink. Do not use the same thumbtack holes twice.
6. Repeat 3, but use the following copy: Do not use the dividers as reamers, pincers, or picks. Do not oil the joints of instruments. Do not jab the points of dividers into the drawing board. Always clean instruments before putting them away. Always release the tension in bow instruments before putting them up. Do not screw the nibs of a pen too tight.
7. Repeat 3, but use the following copy: A pen used in ordinary ink should never be used to letter with drawing ink. Do not use a jackknife or other instrument to scrape dried ink off pens of any kind. An ink bottle should never be left uncorked. Ink should not be diluted. Thick ink should not be used. Ink once frozen should be discarded.
8. Repeat 3, but use the following copy: Do not draw backward over a pencil or an ink line. Do not hold the pen over a drawing when filling. Do not pull the ink bottle quill through the nibs of the pen while filling. It will flip ink on the drawing. Hold the ruling pen nearly vertical when inking. Keep instruments sharp.
9. Repeat 1, but use vertical letters.
10. " 2, " " " "
11. " 3, " " " "
12. " 4, " " " "
13. " 5, " " " "
14. " 6, " " " "
15. " 7, " " " "
16. " 8, " " " "

### Group 3-II. Title Design

1.-5. The following titles, Exercises 1 to 5 inclusive, should be laid out as illustrated in Figures 12-II (page 9) and 13-II (page 14). Before the work is begun the student should determine the space necessary, the various styles of lettering to be used for each title, and the weight of each individual line. He should know that the most important lines in the title can be advantageously displayed by assigning them heavier weights and by using the more artistic styles of lettering. For the sake of contrast, less important lines should be subordinated by using plane, lightface letters. Title V, Exercise 5, may be changed to correspond to the student's own university or college.

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Standard Steel Bridge

Span-----Ft. Roadway-----Ft.

Class C Loading

State Highway Department
Bureau of Bridges

Columbus, Ohio--------February, 1930

I

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Map of Idaho

Showing

Drainage Basin
of the
Upper Snake River
and
Tributaries

William S. Todd, C. E.

July, 1935 ----- Scale 1" = 10 Mi.

II

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Stephens-Adamson Mfg. Co.,
Aurora, Illinois

Sagamore Mine Plant
of
John A. Savage & Co.

September, 1927 ---- Scale 1/4" = 1'-0"

Drawn by R. H. M. ----- No. 64053-B

III

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Bailey Milles Company
Victory, Texas

Detail Drawings for East Portal
St. Marks Church
of
Belton, Texas

June, 1931 ------- Scale 1/2" = 1'-0"

Drawn by A. R. O. ------- No. 51380-A

IV

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University of the West
College of Engineering

Cover for Plates in
Engineering Drawing

John Hancock-----May, 1932

V

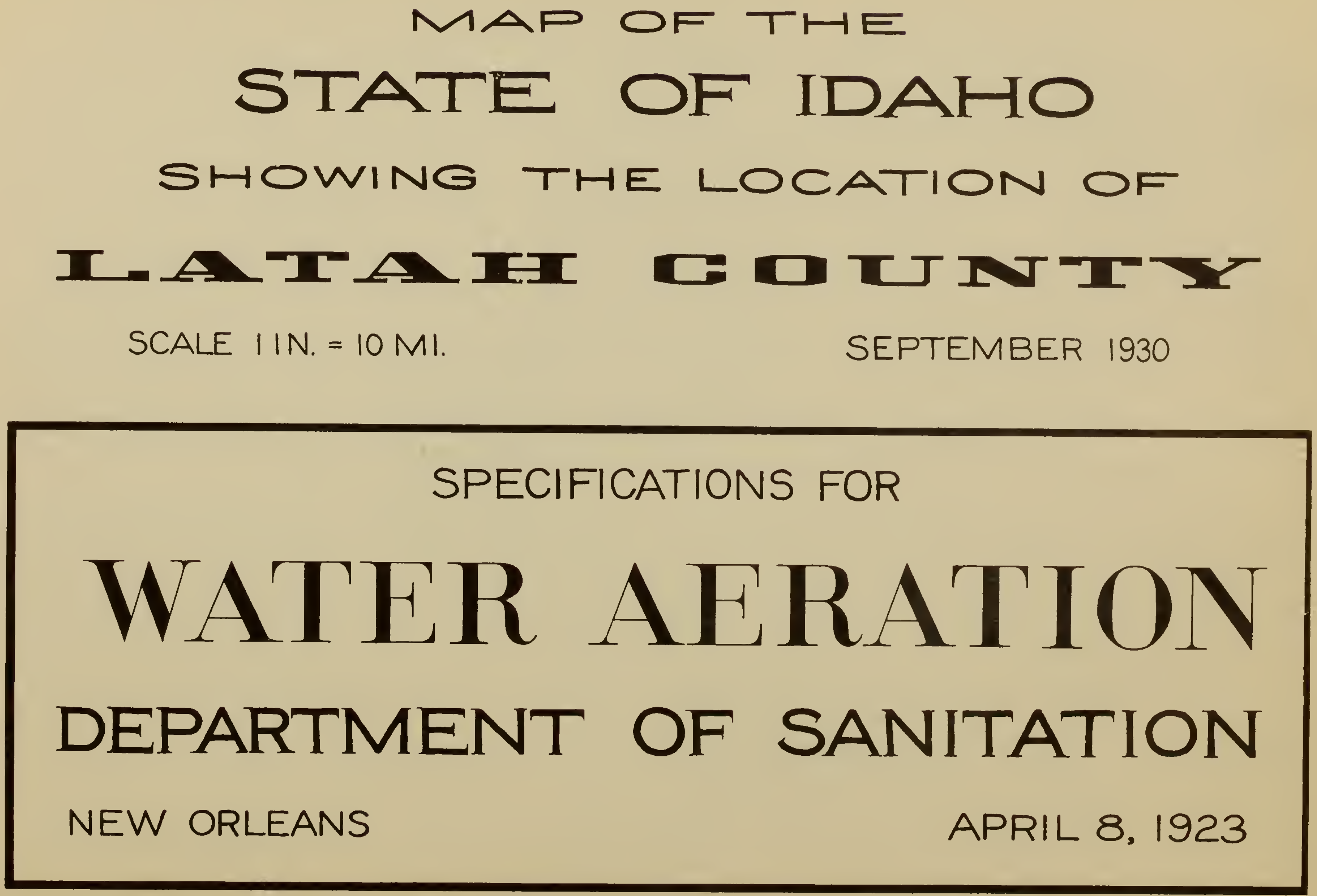


Figure 13-II. Display Titles

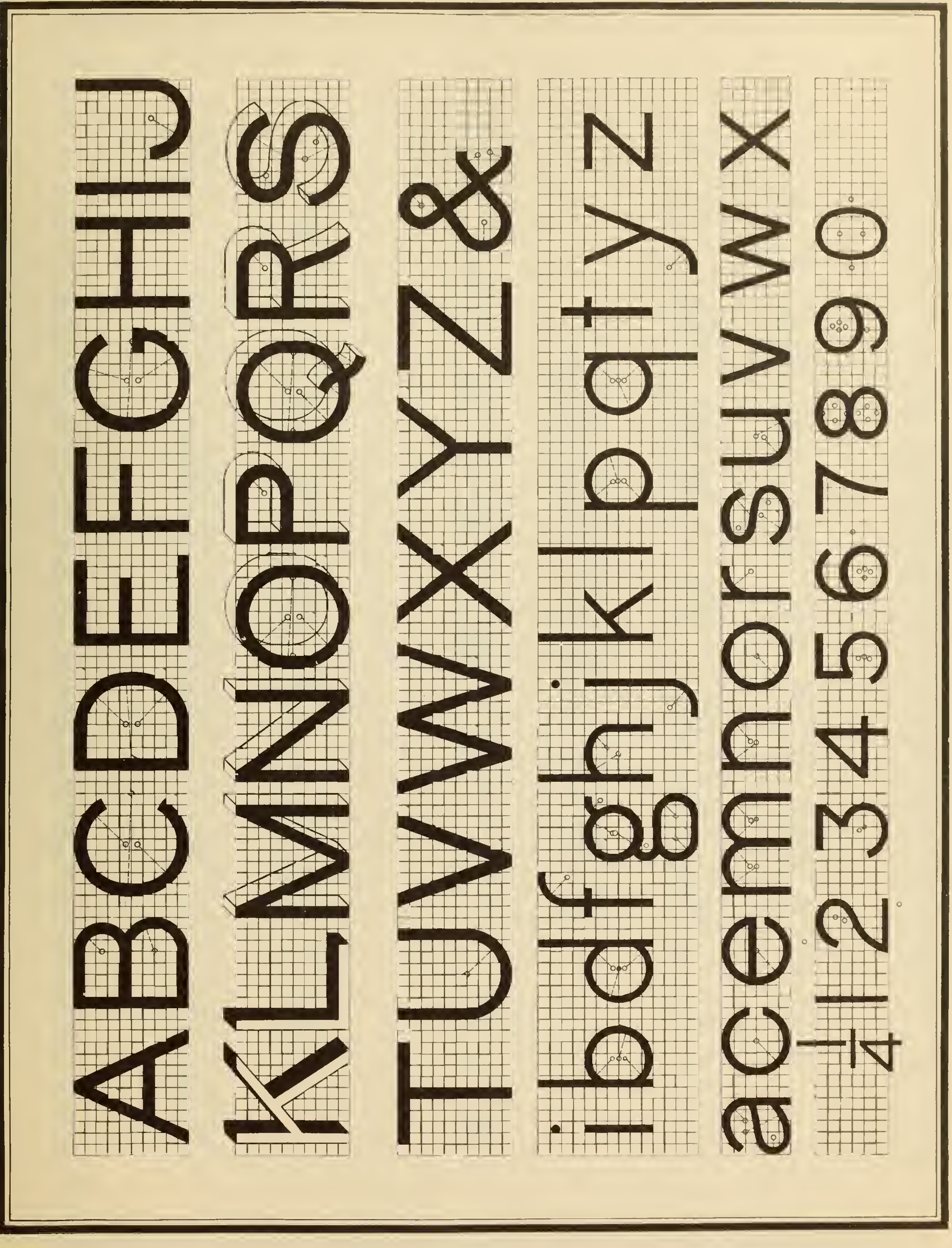


Figure 14-II. Commercial Block Letters

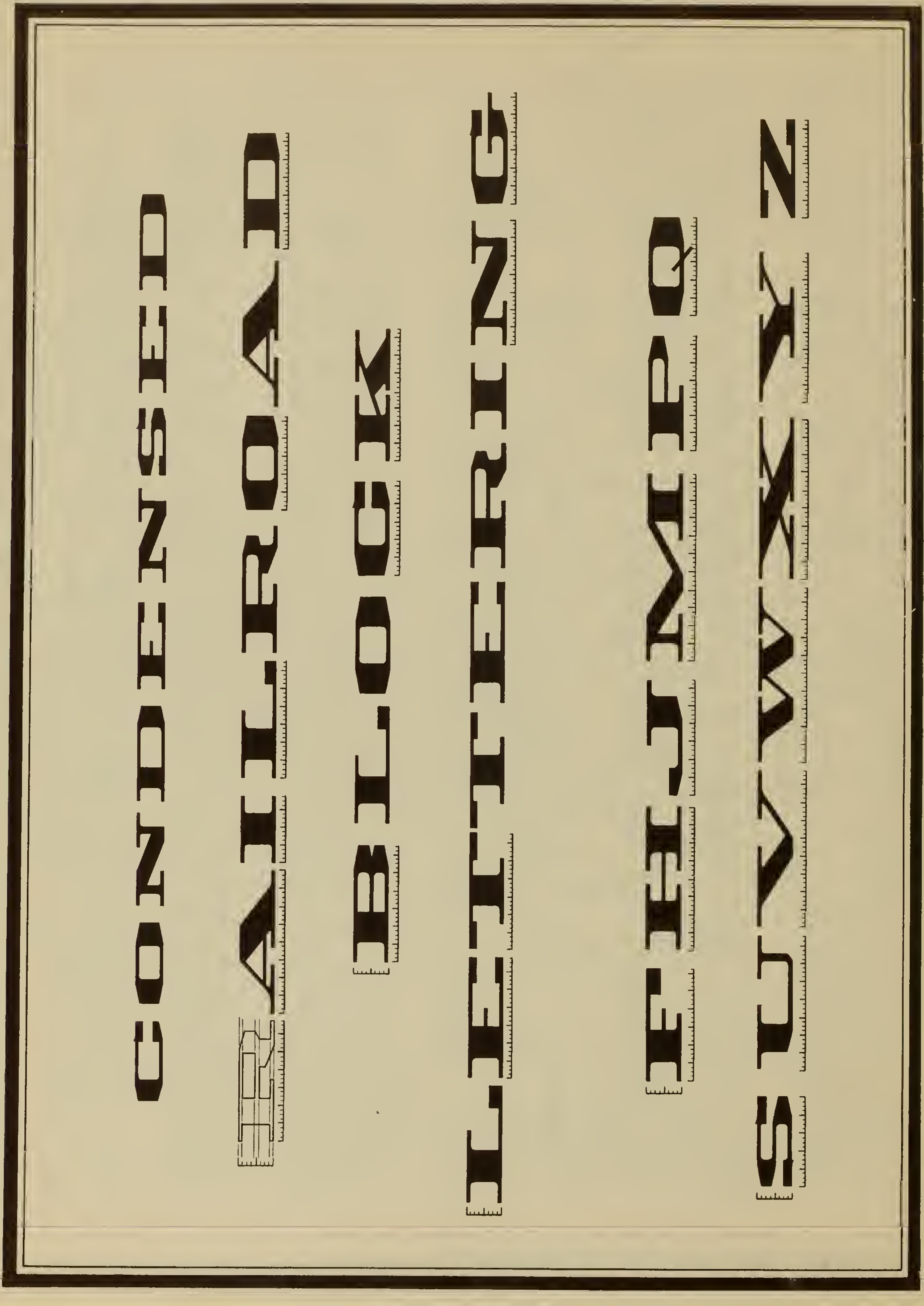


Figure 15-II. Railroad Block

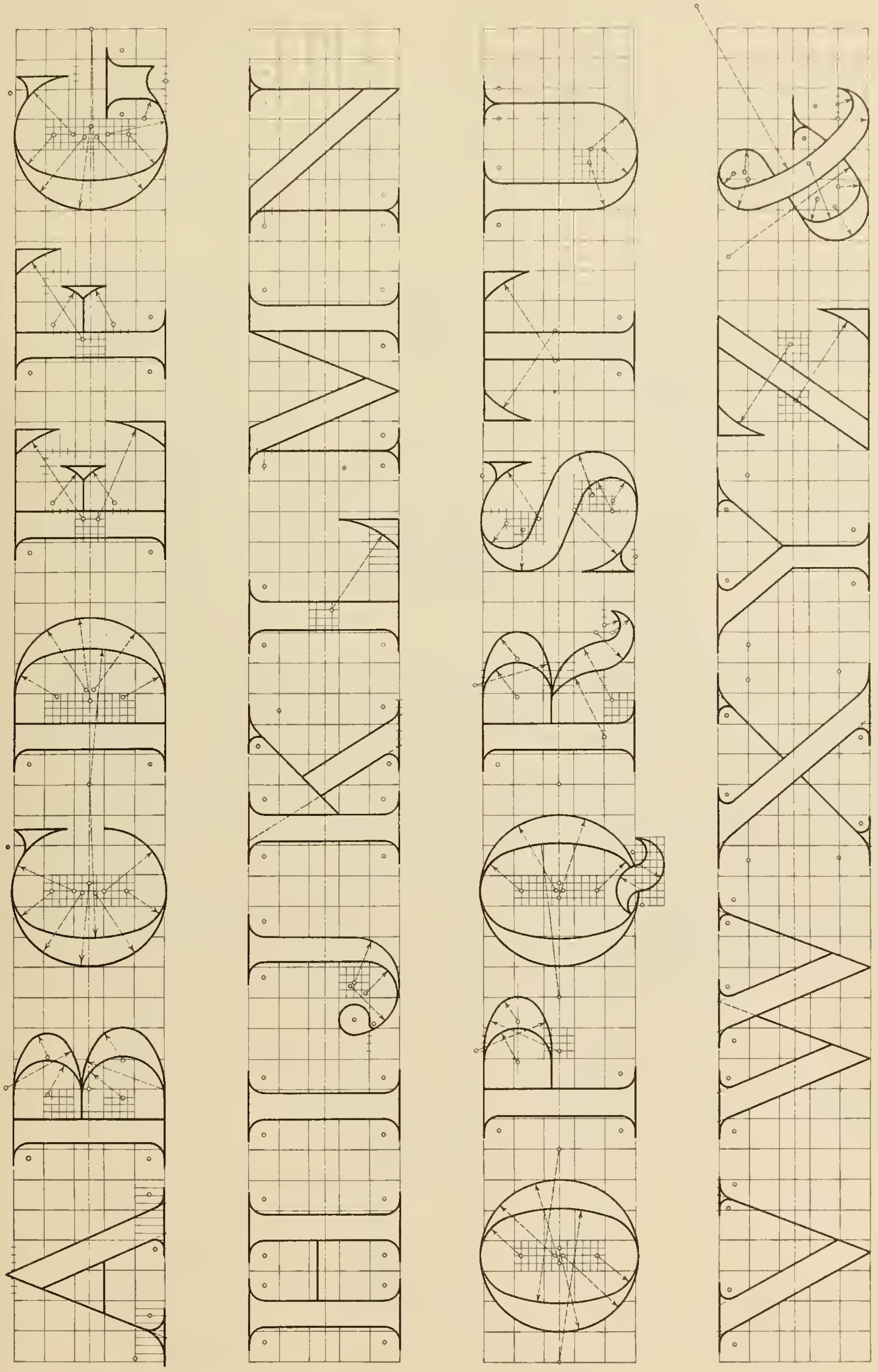


Figure 16-II. Modern Roman Letters

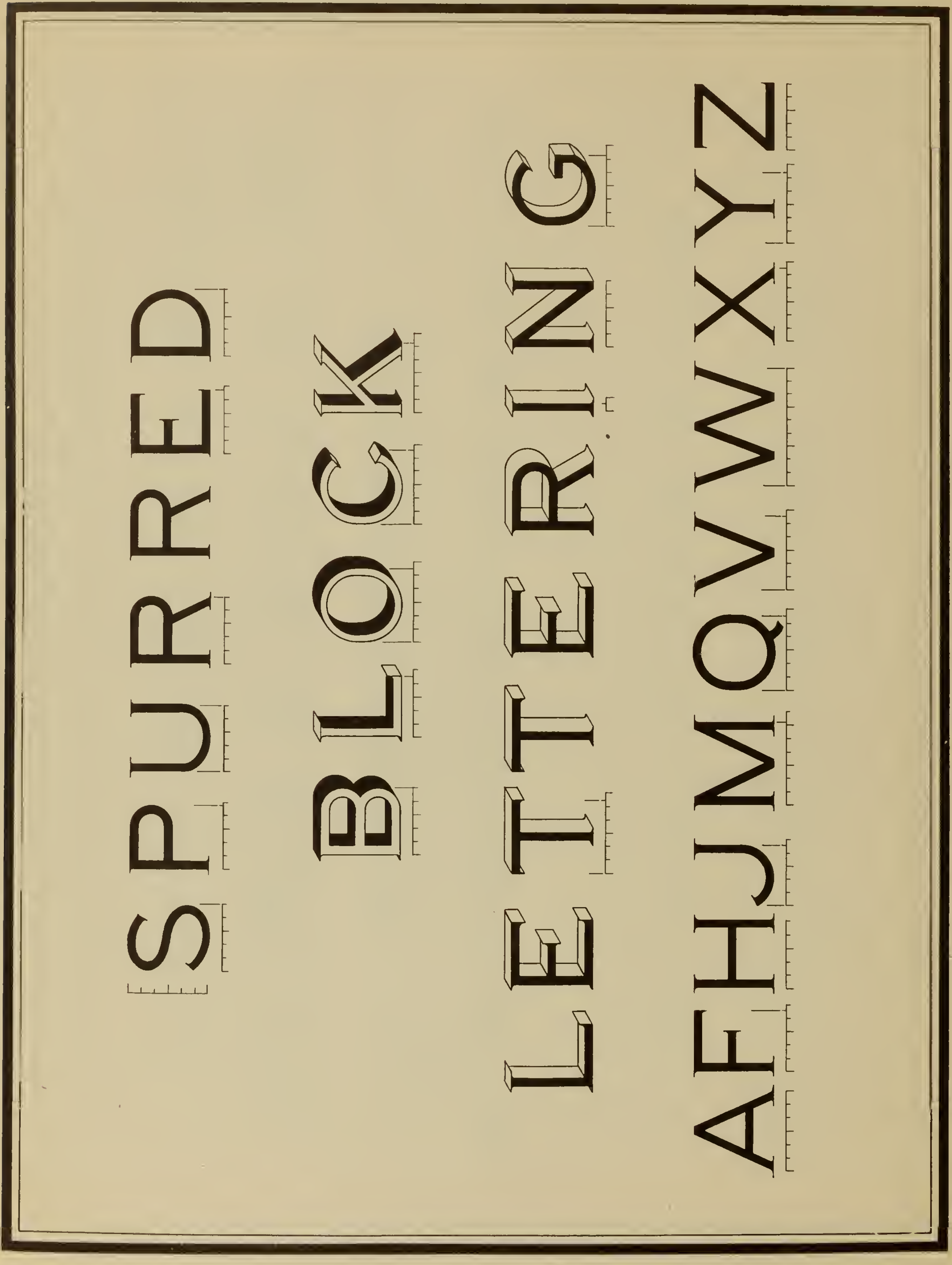


Figure 17-II. Spurred Block Letters

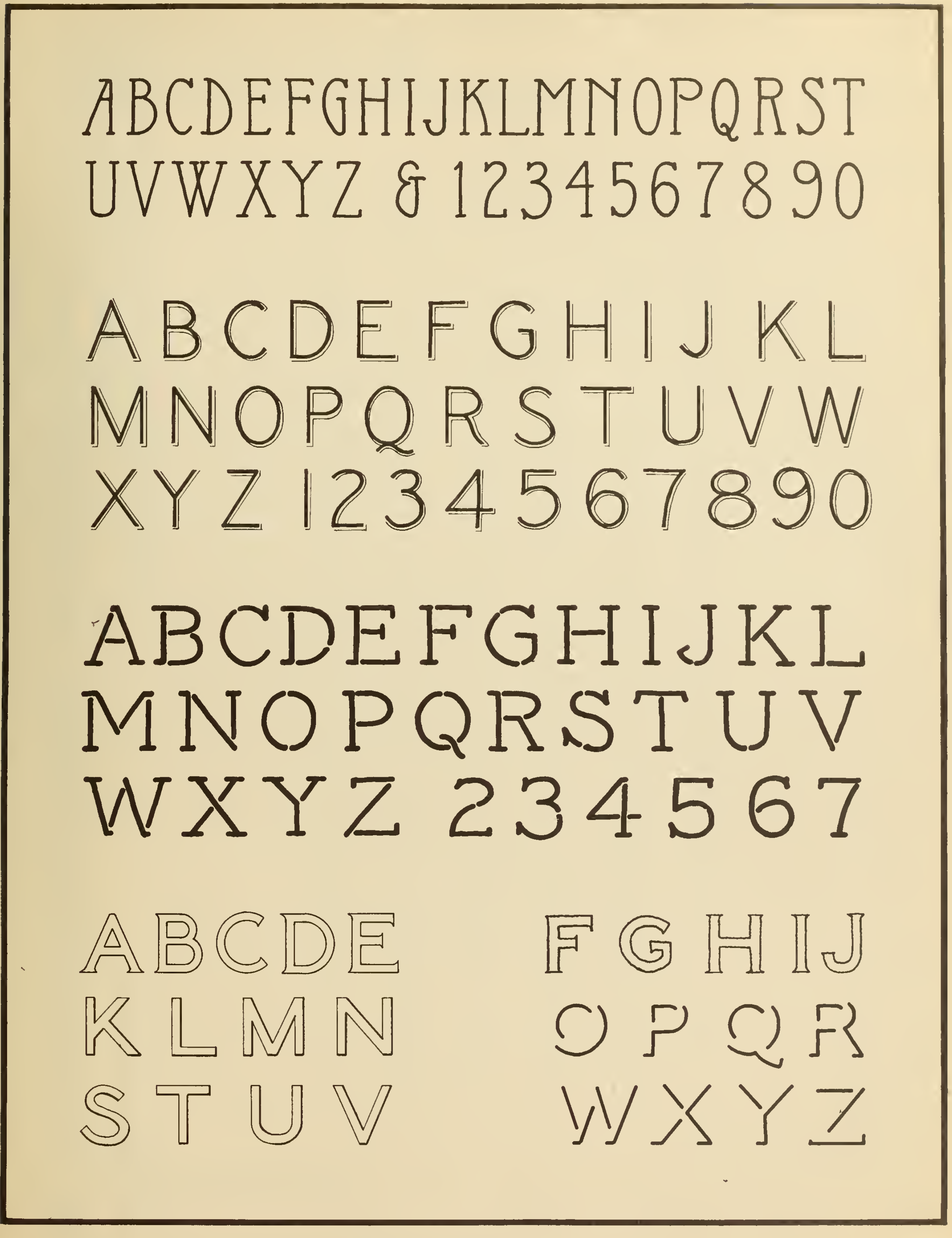


Figure 18-II. Speed-ball Letters

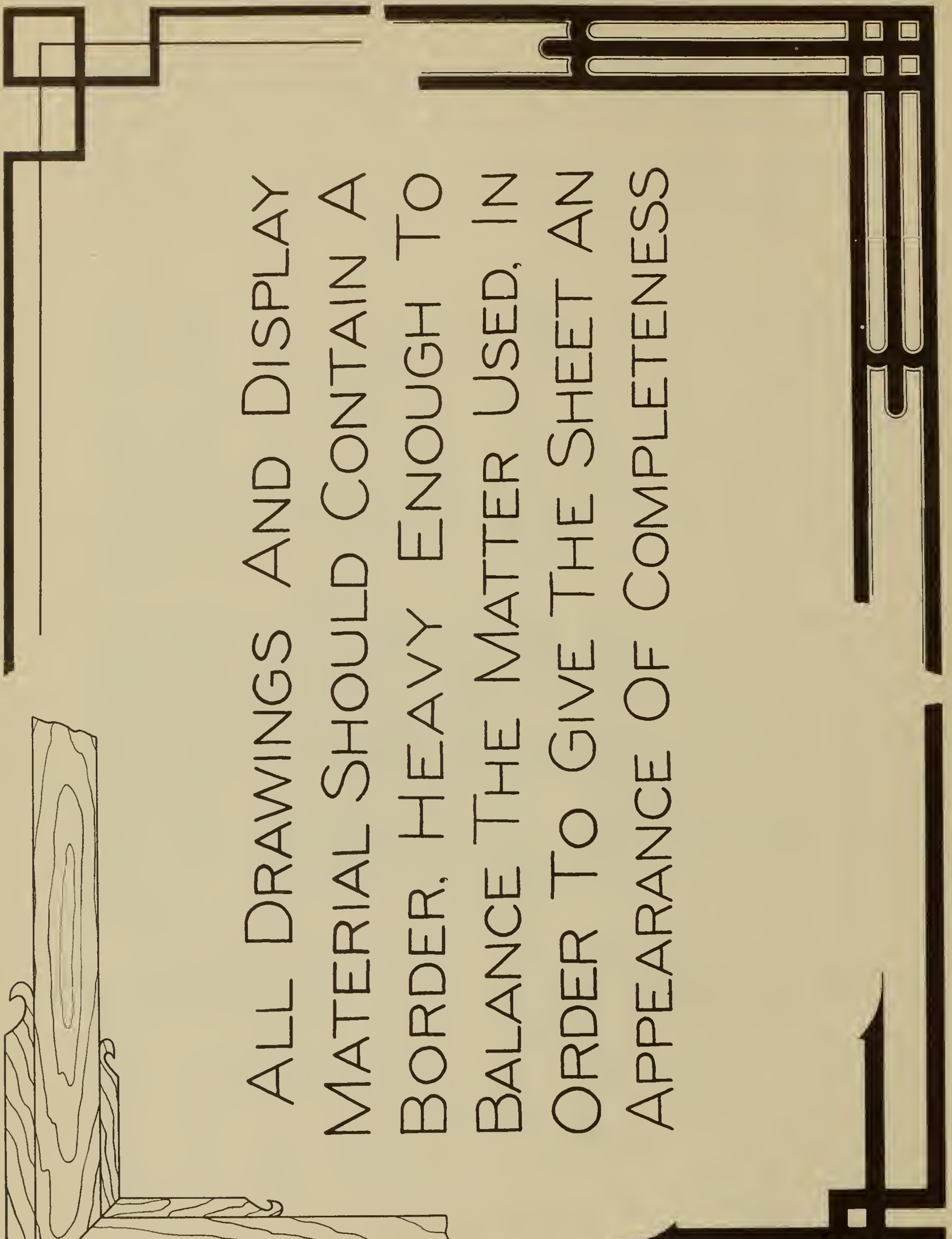

All Drawings And Display
Material Should Contain A
Border, Heavy Enough To
Balance The Matter Used, In
Order To Give The Sheet An
Appearance Of Completeness

Figure 19-II. Border Designs

## CHAPTER III

## USE AND CARE OF DRAWING EQUIPMENT

1-III. It is necessary for an engineer to know drafting-room methods and practice, whether he be in the design, drafting, construction, or operation and maintenance department. His work is constantly placing him in contact with the drafting room. He also uses the drawings and specifications turned out at the drafting offices. The way to become proficient in reading and handling drawings is to study the fundamental principles of making them. A study of these principles can best be accomplished by application in making the drawings. To become proficient in the art of drawing, the student must first know the technique of handling his instruments and other drawing equipment. There is a technique in drawing as in other lines of work which require skillful operations or dexterous manipulations.

Good form, i.e., proper technique, of handling drawing equipment should be insisted upon throughout this course and subsequent drawing courses. It may seem awkward enough to the beginner, but an experienced draftsman can appreciate the application of drawing technique. It enables one to speed up his work and turn out better drawings at the same time. The beginner, therefore, should ever bear in mind the following instructions in the use and care of drawing equipment.

The essential items which go to make up a draftsman's outfit are shown in Figure 1-III on page 23. The use and care of the individual items will be explained in detail later.

2-III. Pencils. All work on a drawing, except the lettering, should be done with a hard pencil. A soft pencil leaves an excess of pencil dust on the drawing which will result in a smear when the T-square and other equipment are run across the lines so drawn. To avoid this, a hard pencil should be used for drafting, the degree of hardness depending upon the kind of paper used. Usually a 4H or a 6H pencil will do. The lettering should be put on a drawing last to prevent smears. A soft pencil should be used for lettering or sketching. An F or H is recommended. In all cases the pencil should be kept sharpened and well pointed. Penciling should always be done light. A heavy hand will put creases in the paper which will result in kinky or wavy lines when the penciling is inked.

The pencil should be sharpened to a long, slim, conical point, leaving about 3/8 of an inch of the blunt lead exposed. The pencil is then pointed on a sandpaper pad, Figure 1-III, E. The wedge and chisel points, in addition to the conical, are often used to advantage by an experienced draftsman, but they are not recommended for beginners. The pencil should be held nearly vertical, leaning slightly in the direction the line is to be drawn. The wood of the pencil should not touch the straightedge. That is, the top of the pencil should lean away from the draftsman, but the pencil lead should be held firmly against the straightedge. The pencil should be turned constantly in the fingers while penciling is being done. This will insure an even, conical point until the pencil needs sharpening again. Neither end of the pencil should be put in the mouth.

3-III. Drawing Board. The true edges of a drawing board are the two strips which are dovetailed or tongue-and-grooved into the body of the board. These strips should normally come to the right and left of the draftsman. The top and bottom of the board are not true and should never be used as a guide for the T-square. A right-handed person should draw with the head of the T-square to the left. A left-handed person should use the reverse form. The T-square head should not be switched from one edge of the board to the other. In the course of time, either the T-square or board, or both, is almost sure to become slightly out of true. If the head is always kept on the same edge of the board, the error will be compensating.

For a right-handed draftsman the board should preferably be placed so that the light will come from the left and front.

4-III. T-square. As previously stated, the head of the T-square should be placed on the left edge of the drawing board and kept there (Article 3-III). Obviously, the T-square is used primarily for drawing horizontal lines. These lines should be drawn from left to right. Vertical lines should be drawn with the T-square and triangles,

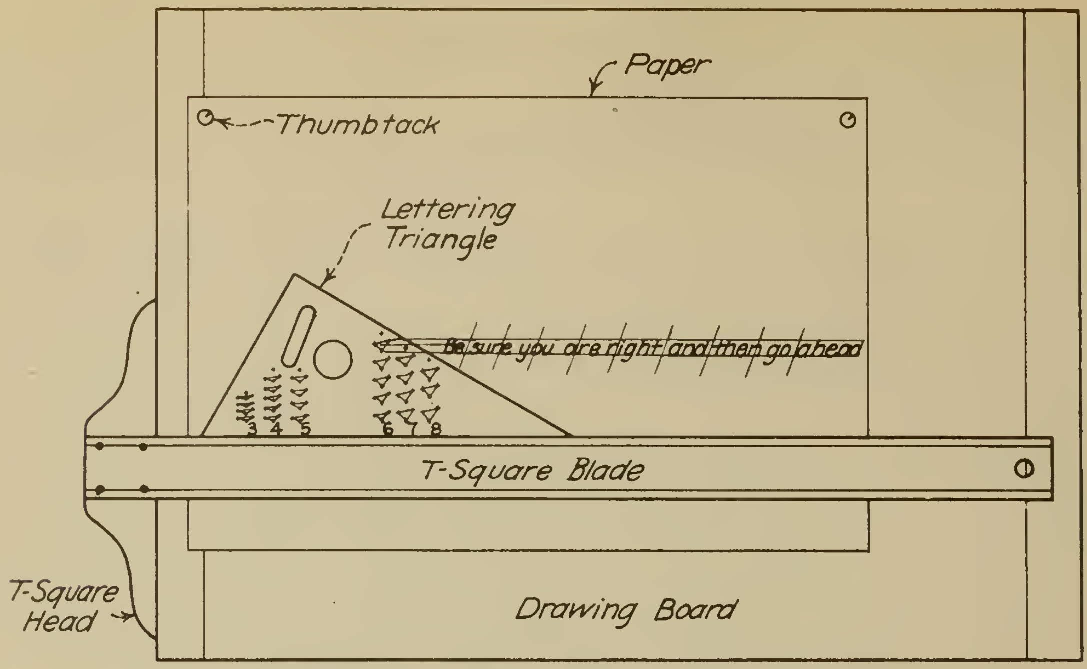


Figure 2-III. Drawing Board, T-square and Triangle

Figures 2-III and 3-III. A check should be applied often to see that the T-square blade has not slipped, especially when working out near the end of the blade. This is done by releasing the T-square, pressing the head lightly against the board, and then running the fingers along the blade in order to hold it in the proper position. Weights should not be placed on the T-square to hold it in place. The paper, if much smaller than the board, should be placed at the lower left-hand corner, but up several inches from the bottom. A true edge of the paper, in case the sheet has been cut, should be placed at the top and lined up even with the top edge of the T-square. The paper can then be held in place, the T-square slipped down, and a thumbtack put in each upper corner and pressed firmly into position. If the sheet is not too large, the two tacks in the upper corners will be sufficient. A draftsman should always avoid running the T-square over thumbtacks. When a drawing is put back on a board the same thumbtack holes should not be used again.

5-III. Triangles. A draftsman's outfit should have at least one 45-degree triangle, one 30-60 degree triangle, and a lettering triangle, Figures 1-III and 2-III. As previously pointed out, vertical lines are drawn by means of the triangle placed against the T-square. A triangle, when being used, should be placed against another straightedge, usually the T-square, but another triangle is sometimes used. A line should never be continued until a corner of the triangle is reached. An inaccuracy in the line is likely to occur.

The common angles used so much in drafting can be laid out by combinations of the triangles and straightedge. They are the multiples of 15 degrees, i.e., 15, 30, 45, 60, 75, 90, 105, etc. These angles can be laid out much faster by the use of the triangles, and the construction is much more accurate than when the protractor is used. For this

Figure 1-III. The Essential Items Composing a Drawing Outfit. A, soapstone. B, triangular architect's scale. C, lettering triangle. D, thumbtacks. E, pencil pointer (emory pad). F, hone. G, H, L, M, lettering pens. I, penholder with pen point. J, "F" pencil. K, "4H" pencil. N, 45 degree triangle. R, 30-60 degree triangle. O, ink eraser, sanded. Q, eraser, soft for cleaning. P, waterproof drawing ink, black. T, T-square with head placed on the left vertical edge of the drawing board, S. U, irregular (French) curve. V, protractor. X, erasing shield. Y, dust cloth. Z, blotter. W, drawing instruments composed of (a) Swedish detail pen, (b) ruling pen, (c) spring bow pencil, (d) spring bow dividers, (e) spring bow pen, (f) center tack to be used when drawing concentric circles, (g) extension bar for compasses, (h) extension bar for compasses to be used as a holder for pen (j), (i) lead case and leads, (j) pen for compasses (m) and for inking irregular curves when used in holder (h), (k) screw driver containing screw points for bow instruments and compass, (l) dividers, (m) compasses.

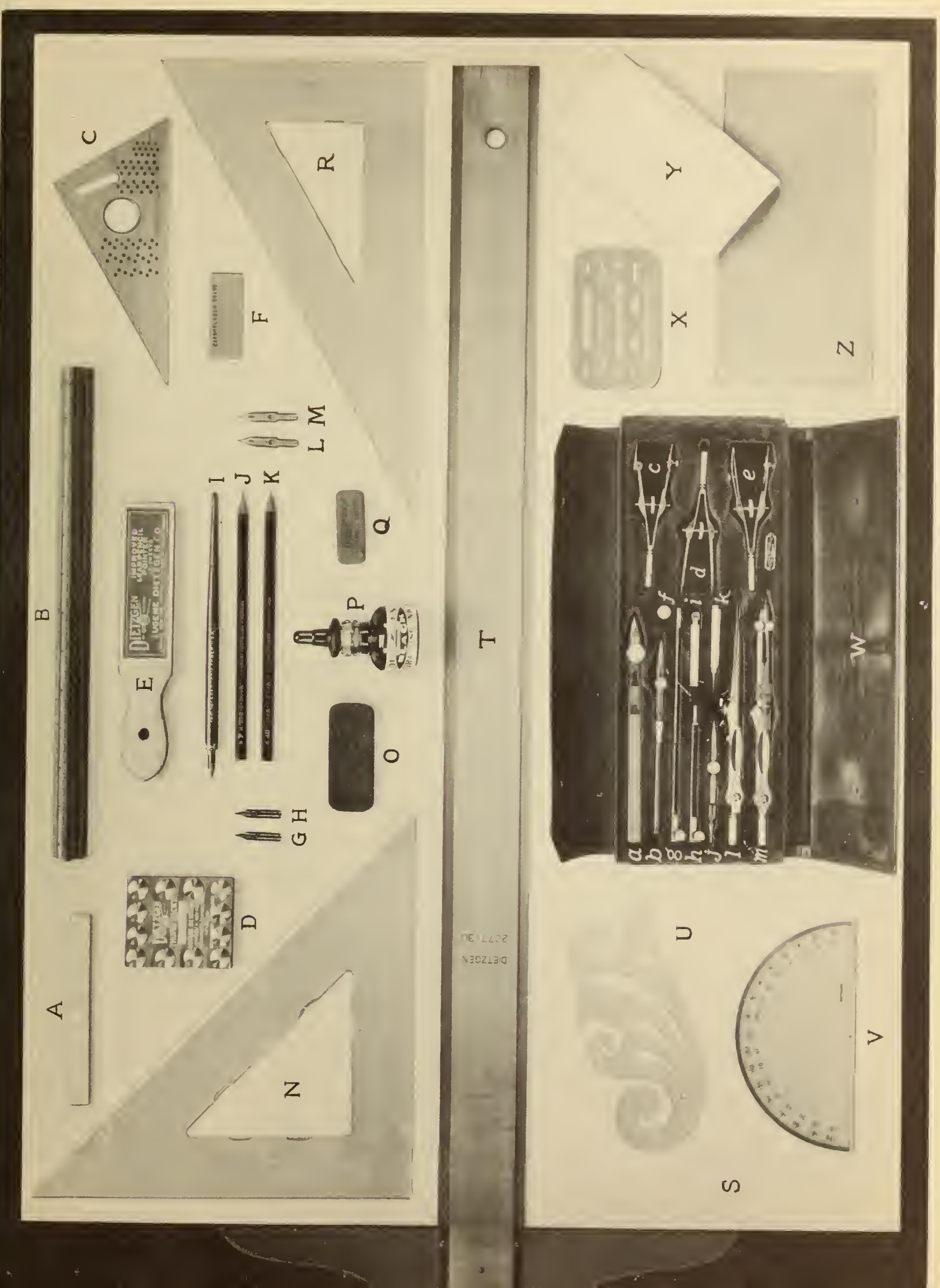


Figure 1-III. (Drawing outfit described at the bottom of page 22.)

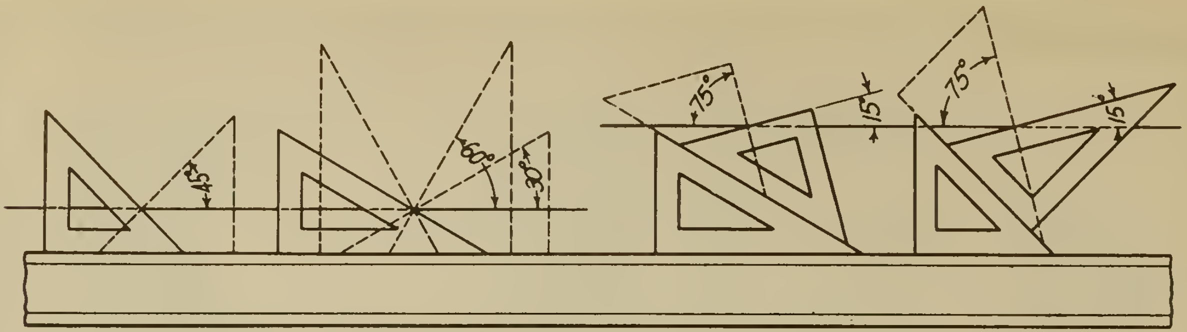


Figure 3-III. To Draw the Common Angles

reason the protractor, Article 13-III, should not be used when constructing the common angles.

Guide lines should always be drawn for lettering. An experienced draftsman might draw only one guide line when he is making letters of the height which he is accustomed to make. A beginner, however, should draw the base and cap lines when he is making capitals and numerals and should draw all three guide lines when making lower-case letters. This will apply even though a single letter or numeral is being made. A lettering triangle should always be kept handy and used when guide lines are to be drawn. An application of this labor-saving device is illustrated in Figure 2-III.

To draw parallel lines: Place a triangle against the T-square or another triangle, move the two along until one edge of the triangle comes in contact and coincides with the given line. Hold the straightedge firmly, and slide the triangle along until the place is reached where the required line is to be drawn. Hold the triangle and straightedge with one hand and draw the parallel line with the other.

To draw perpendicular lines: One line given: Place the hypotenuse of a triangle against a straightedge. Move the two until a leg of the triangle coincides with the given line. Slide the triangle along until the other leg reaches the point on the given line where the required perpendicular line is to be drawn. The perpendicular line can now be drawn.

6-III. Scale. A scale is defined as a piece of metal, wood, or other material graduated with lines for use in making measurements. In some instances the scale refers solely to the graduations on the article. Scales are usually made of boxwood and are often called "boxwood scales." In this sense, "scale" refers to the article and not to the graduations. The terms are used indiscriminately. A ruler is a straightedge to be used as a guide for marking or drawing straight lines (right lines). It will damage a scale to use it as a ruler. Figure 4-III illustrates an architect's scale and the manner of laying off dimensions on a machine drawing and a structural drawing. Scales are made flat or triangular in section. The triangular sections are most commonly used. The architect's scale (or mechanical engineer's scale) is divided into proportional feet and inches. The architect's half-scale, i.e., a reduction of one-half, is written, scale 6" = 1', and is used by structural draftsmen. The mechanical engineer's half-scale is written, scale 1/2" = 1", and is so used on machine drawings. The unit, 1, comes last in both cases. The scale for structural drawings is illustrated at the left end of Figure 4-III. A length of 2' - 2 1/2" is represented. It can be seen that one end of the measurement terminates with the fifth division to the left of zero. The machine drawing scale is at the right end. A length of 3 3/16" is represented. One end terminates 2 1/2 divisions to the right of

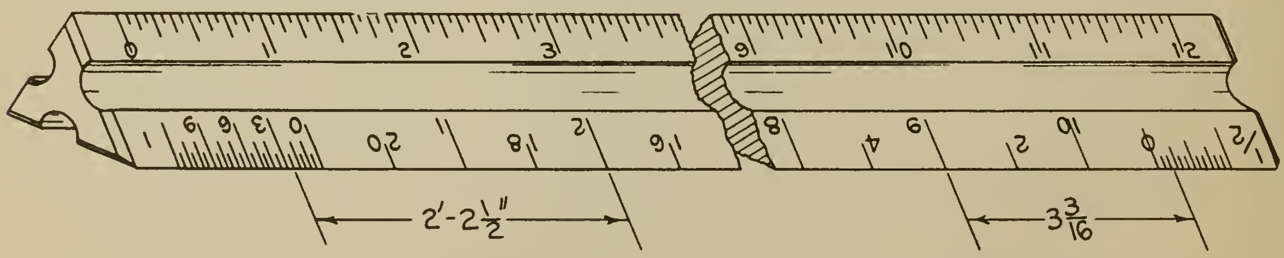


Figure 4-III. The Triangular Architect's Scale

zero. The scale used on maps is divided into decimals of an inch, i.e., 10, 20, 30, 40, 50, and 60 divisions to the inch. It is called the engineer's scale (or civil engineer's scale), and is written, scale 1" = 50', etc. The unit, 1, comes first.

7-III. Compass. The compass, Figure 5-III (page 26), is used to draw circles and circular arcs with radii of three-quarter inch and larger. The smaller circles and arcs are drawn with the bow instruments. The needle point in the compasses should be adjusted for both the pencil and pen before the instrument is put in use, and the adjustment should not be changed afterward. The pen should be put in the compass, and the needle point (the point with the shoulder) adjusted so that it is slightly longer (approximately a thirty-second of an inch) than the pen, so when the point sinks into the paper the pen will be perpendicular to the board and just touching the paper when the instrument is vertical. The pencil point should be changed, as it wears down, to fit the needle point. A hard lead should be used in the compass, 4H or 6H. As a rule, the leads that come in instruments are entirely too soft. The pencil should be sharpened with a beveled (chisel) point with the inclined edge of the bevel turned outward. Joints of the compass should never be oiled. On the contrary, they should be kept tight and firm so they will be fairly difficult to turn. The legs of the compass may be kept straight when drawing small circles, say up to 1 1/2-inch radii. For drawing larger circles the legs of the compass should be adjusted so both will be perpendicular to the paper, when the instrument is being operated. This especially applies when the pen is being used.

When circles larger than nine or ten inches in diameter are to be drawn, the pen or pencil, whichever happens to be in use, is removed, the lengthening bar inserted, and the pen or pencil replaced in the end of the bar. The instrument is then operated as before, and circles with radii up to nine or ten inches can be drawn. To draw larger circles a beam compass should be used.

The compass should be held lightly in one hand, the handle (vertical stem at the top) turned gently between the thumb and forefinger, keeping the handle almost vertical--leaning slightly forward--while the circle is drawn in a clockwise direction. Once around will be sufficient. The pen should be filled with the quill of the ink bottle by inserting the quill full of ink between the nibs of the pen. The quill should not be drawn through the pen. This will flip ink on the paper.

8-III. Dividers. The divider, sometimes called the spacer, Figure 6-III, is an instrument for dividing lines--curved or straight--and for transferring distances. This instrument should by all means have a hairspring adjustment. The divider should be set at approximately the desired distance, and then by means of the hairspring adjustment the instrument can be adjusted accurately to the desired distance.

To divide a line into a given number of equal parts: Set the divider at what is thought to be the required distance. Make a trial division. The line doubtless will not be divided into the required number of

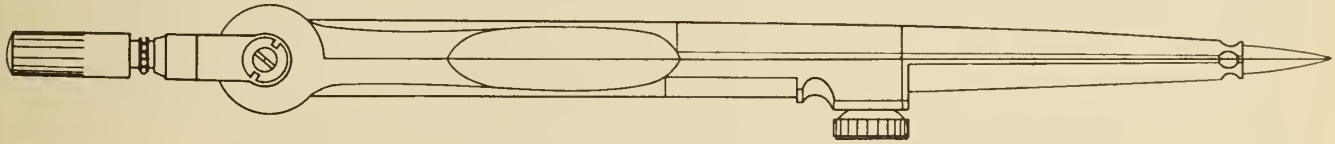


Figure 6-III. The Divider

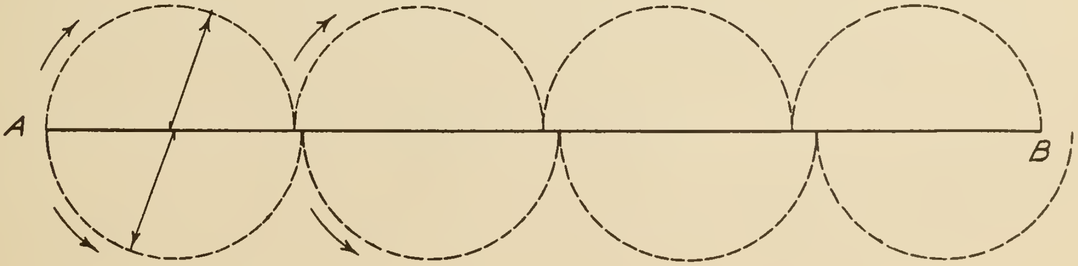


Figure 7-III. To Divide a Line

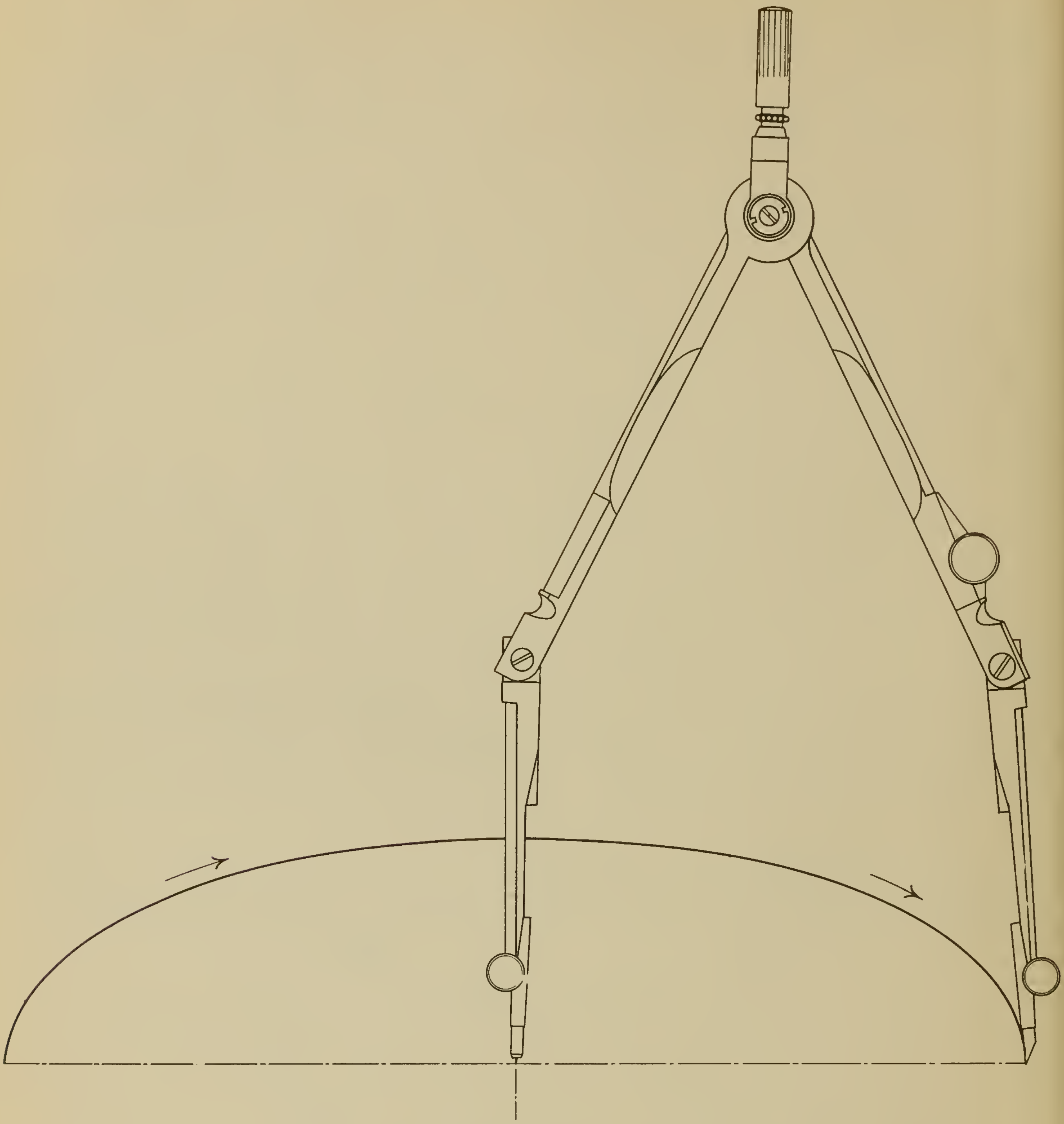


Figure 5-III. The Compass

equal divisions, Figure 7-III on page 25. If the line is overrun, shorten the spacing of the divider and make another trial division. The operation is to be repeated until the line is divided as required. This operation might seem quite impossible at first, but with a little experience the desired division can be quickly and accurately made.

The spacer should be oscillated back and forth between the thumb and forefinger and not rolled, as in the case of the compass.

9-III. Ruling Pen. The ruling pen, sometimes called the right line (straight line) pen is the most used and probably the most important instrument in the draftsman's outfit. It should be of excellent quality. For general utility the Swedish detail pen is recommended, Figure 8-III. The ruling pen is for inking straight lines after they have been made in pencil, using a straightedge as a guide. Instruments, especially the pens, should be kept well sharpened. The nibs of the pens should be ground back to a slim, even taper--not dubbed off--the points should be even, and the flat sides of the nibs rounded off until they conform to the shape of a parabola. The pen should not be sharp enough to cut into the paper.

The nibs should be screwed fairly close together and filled with ink to about three-sixteenths of an inch above the point. The pen is filled with ink by inserting the quill (which forms a part of the bottle stopper) between the nibs of the pen. The quill should not be pulled through the nibs but should be withdrawn in the same manner in which it was inserted. Pulling the quill through the nibs will flip ink. A pen should not be filled over a drawing. The pen can then be adjusted to the proper weight (thickness of line) by making marks on paper, similar to the paper on which the drawing is to be made, using a straightedge as a guide and watching the thickness of the proper line listed in the chart of Conventional Lines, Figure 12-III.

The pen should be held so that both nibs touch the paper, i.e., in a vertical plane, but leaning only slightly in the direction of inking. If the pen is leaning toward the draftsman, not vertical, a ragged line will probably be the result. If it is leaning away from the draftsman, not vertical, the ink will run under the straightedge. Ink should never be allowed to accumulate on the outside of the nibs. If this occurs, the ink will be sure to make contact with the straightedge and run underneath.

Faulty lines are an indication of poor drawing technique. The draftsman either does not know how to keep his pens in order or he does not understand how to use them. Long lines should be drawn or inked with a slow movement of the entire arm, letting the nails of the two smallest fingers slide along the straightedge, ceasing the arm movement near the end of the line, and finishing out the line with a finger movement. Short lines should be inked with a finger movement.

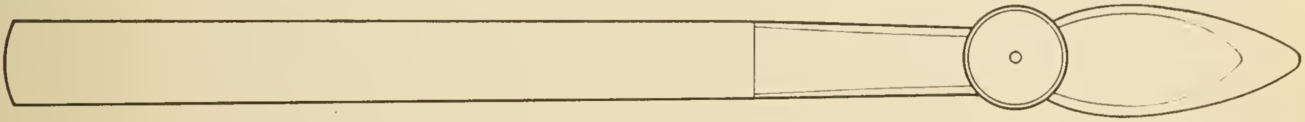


Figure 8-III. The Swedish Detail Ruling Pen

10-III. Curve Line Pen. Curve lines should be inked with a curve line pen, i.e., a pen having curved nibs, such as the pen for the compass. The curve pen for inking irregular curves (ellipses and the like) is made by putting the compass pen in a specially prepared handle or stock which comes with the set. In case the set does not contain a special stock, the compass extension bar can be used to hold the curve pen. A ruling (or straight line) pen should not be used to ink curve lines. An irregular curve (French curve) is used as a guide in inking irregular curve lines. The use of irregular curve will be explained later.

11-III. Bow Instruments. The spring bow instruments, Figure 1-III, (c), (d), and (e), are used for small construction. They are the bow dividers, bow pencil, and bow pen, and serve the same purpose as similar instruments of larger sizes. The bow instruments are much more convenient to handle, and work goes much more rapidly on small construction than is the case when larger instruments are used.

The needle point adjustment for the bow pencil and bow pen is the same as for the compass. The pencil lead should be replaced with a 4H or 6H lead about an inch long and sharpened with a beveled (chisel) point, as described in Article 7-III. A quarter-inch of the lead, or more, should extend past the holder.

12-III. Irregular Curve. When lines, other than straight lines and circular arcs, are to be drawn, a ruler of irregular shape must be used. This special ruler is called the irregular curve or French curve, Figure 9-III. A sufficient number of points are first determined through which the curve is to pass. The flat part of the curve, as at points 2, 3, and 4, will require fewer points than will the sharper parts, as at points 5, 6, and 7. Usually, enough points are set for the sharp turns, and the same spacing is carried throughout. Work is begun at some point, as at 0.

To draw an ellipse: Determine by a well-established method a certain number of points through which the ellipse is to pass. See the Trammel Method, Chapter IV. Shift the irregular curve until three points coincide with the edge of the curve, say points 0, 1, and 2, Figure 9-III. By means of a light pencil mark, connect only the first two points, i.e., points 0 and 1. Do not connect points 1 and 2, but shift the curve and line up three more points, starting with 2, i.e., points 2, 3, and 4. Now connect only points 2 and 3. Continue around and close the ellipse by lining up points 11, 0, and 1. Connect 11 and 0, and the ellipse is completed. Inking is carried on in the same manner. Using the irregular curve as a ruler, the pencil line is inked with a curve pen, Article 10-III. An insufficient number of points will result in an uneven, bumpy curve, in which case more points should be set.

13-III. Protractor. A circle is divided into 360 divisions called degrees. The degree is divided into 60 divisions called minutes. A minute is divided into 60 divisions called seconds. The relation can be written as: $1^{\circ} = 60' = 360''$.

The common angles should be laid off by combinations of the triangles and a straightedge, as explained in Article 5-III. All other angles will have to be laid off with a protractor, Figure 10-III.

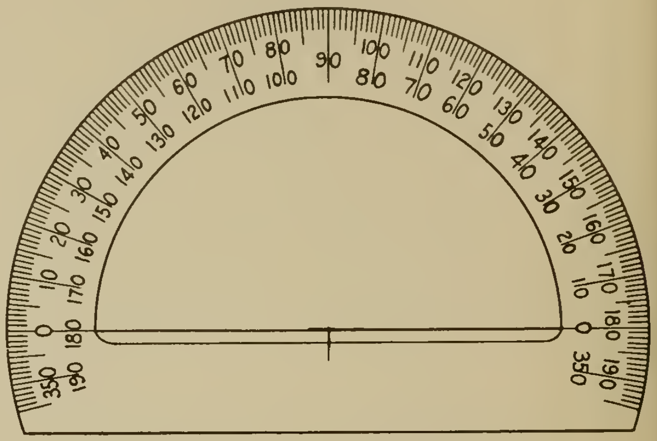


Figure 10-III. Protractor

To lay off an angle of 40° from line AB, above the line and to the left of A,

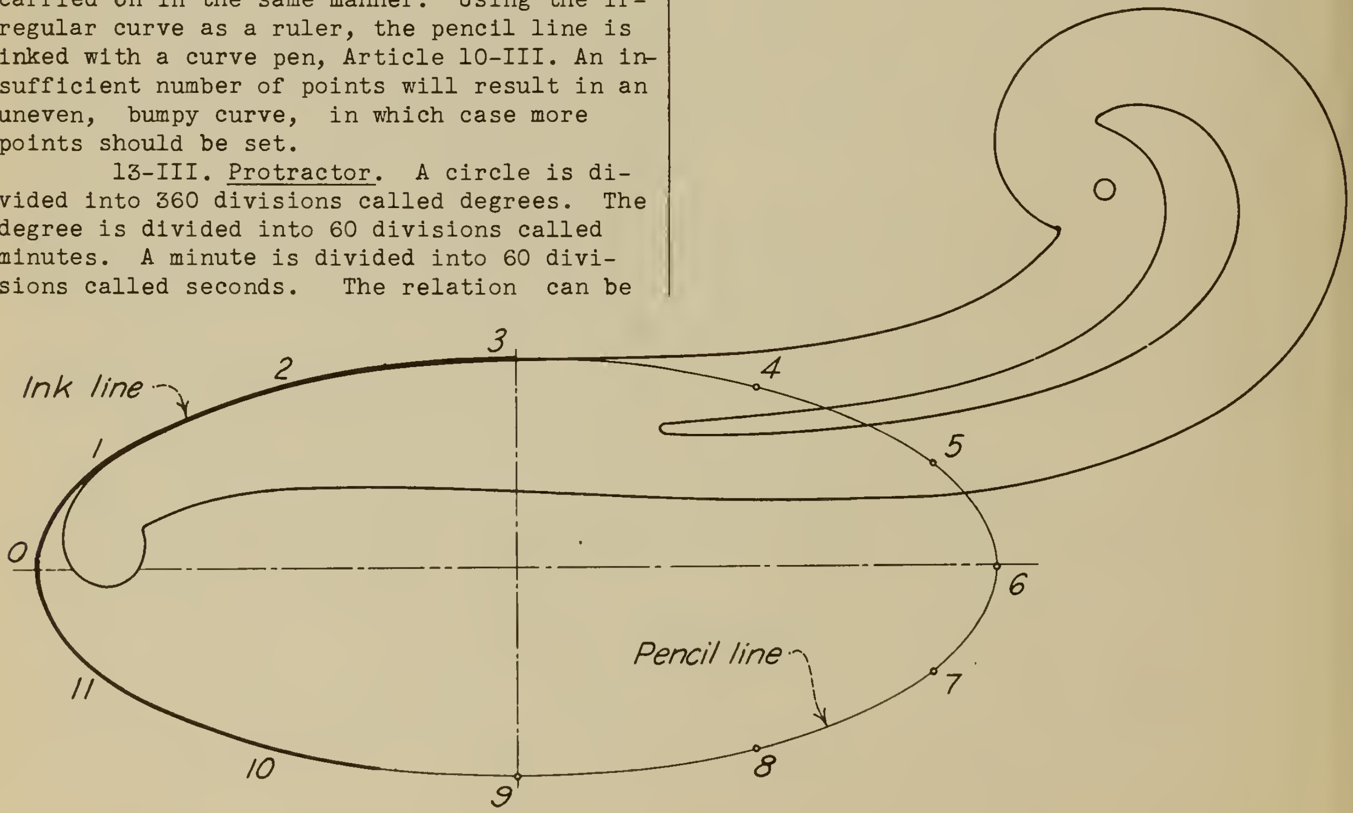


Figure 9-III. Irregular Curve

Figure 10-III. Set the center point of the protractor spoke (the hub) at point A. The center point is usually a line drawn through the middle of the protractor at right angles to the spoke. Place the edge of the spoke, passing through 0-0, along line AB. Starting at the 0 to the left, read up until 40 is seen on the circumference of the protractor. Set point C with a pricker or needle point at 40. Remove the protractor and connect AC with a straightedge. The angle BAC is equal to 40°. A point should not be set by jabbing a hole in the paper with a pencil. If the drawing set does not contain a needle point of some kind (a pricker), then one should be secured.

14-III. Erasing Shield. Erasing shields are usually made of sheet metal and have numerous narrow slots of various shapes cut through the metal through which erasures can be made on a drawing. The shield itself protects the rest of the drawing, Figure 1-III, X. The erasure should be made with a hard rubber eraser, either plain or sanded, or glass wool. Either the sanded eraser or glass wool is preferred for erasing ink lines. Sponge rubber, art gum, or soft rubber eraser is used to clean a drawing after completion. Ink lines should never be scrubbed, for scrubbing takes the life out of them, Article 15-III. After an erasure has been made, the eraser dust should be brushed off the drawing.

Erasures should be made with care, in order not to damage unnecessarily the surface of the paper. This applies especially to erasing ink lines. After ink has been removed, the surface of the paper should be gone over carefully with soapstone and the soapstone patch polished by rubbing the surface with a hard, smooth instrument, such as the jaws of a jackknife. Erasures should not be made with a razor blade, a jackknife, or like instruments. Such erasures are likely to destroy the surface of the paper or tracing cloth and render re-inking almost impossible. These precautions apply especially to beginners.

15-III. Inking. Before the topic of inking is taken up, the reader should review Article 9-III, ruling pen.

In general, curve lines should be inked first and straight lines next (see Article 14-XIV, page 169). Care should be taken to see that tangent lines actually come tangent to the arcs, Figure 11-III, and that "tangent arcs" are tangent. Tangent points (T.P.) and centers of circles and circular arcs should always be marked in pencil and left until after the drawing is inked or the tracing made. A line should never be drawn past its tangent point.

A pencil line should be light, sharp, and well defined. It should be used as a guide for inking. The inked lines should be drawn so that the pencil line splits it in half, i.e., so that measurements can be taken to the center of the inked line.

Pens must be cleaned frequently to remove the dried ink. A jackknife or other metallic instrument should not be used for this purpose. A very weak solution of ammonia will do the trick, but strong ammonia will attack the metal of the pen.

Eraser dust, dirt, or lint should not be allowed to accumulate on the drawing. They are often the cause of "ink runs." The hands and drawing equipment should be washed frequently and kept clean. Moist hands should not touch the paper or cloth any oftener than can be avoided but should rest, preferably, on the drawing equipment (T-square or triangles), or contact can be made with the paper by the finger nails.

Waterproof India drawing ink should be used in lettering or inking a drawing. Ordinary ink should never be used. Pens that have been used in ordinary ink should not be used for lettering or inking a drawing. Drawing ink contains a great deal of drier. After ink becomes thick or dry, it should be thrown away. Ink that has been frozen should not be used. The ink bottle should never be left open. Inked lines should never be gone over backward, when re-inking them.

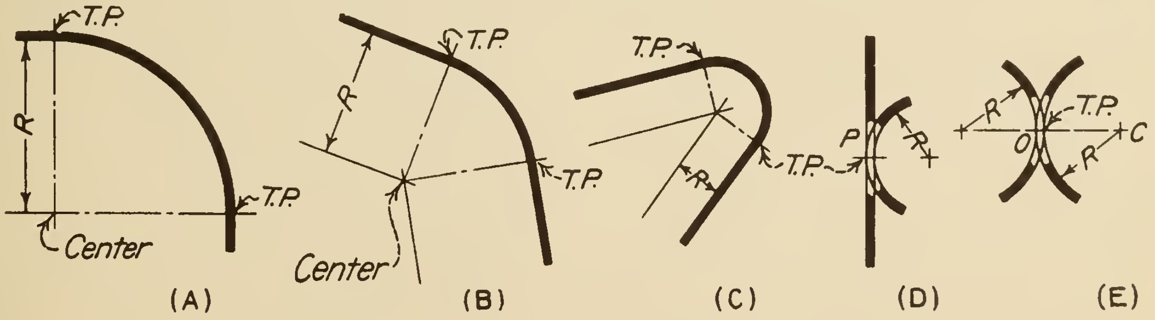


Figure 11-III. Center of Arcs and Tangent Points

16-III. Conventional Lines. In order to add style and improve the appearance of a drawing there must be a well-defined contrast between the various conventional lines composing a drawing, Figure 12-III. Proper line contrast makes a drawing easier and quicker to read. The theme of the drawing, i.e., the visible outline, in the case of object representation, or the curve or figured drawing, in the case of geometrical construction, should be finished, when inked, with a No. 2 line (weight 2). Other lines are less important and therefore should be suppressed. This effect is obtained by varying the weights of the lines according to the importance of the lines. After a drawing is finished, a border should be drawn around it, either plain or figured, but made sufficiently heavy to balance or offset the lines of the drawing.

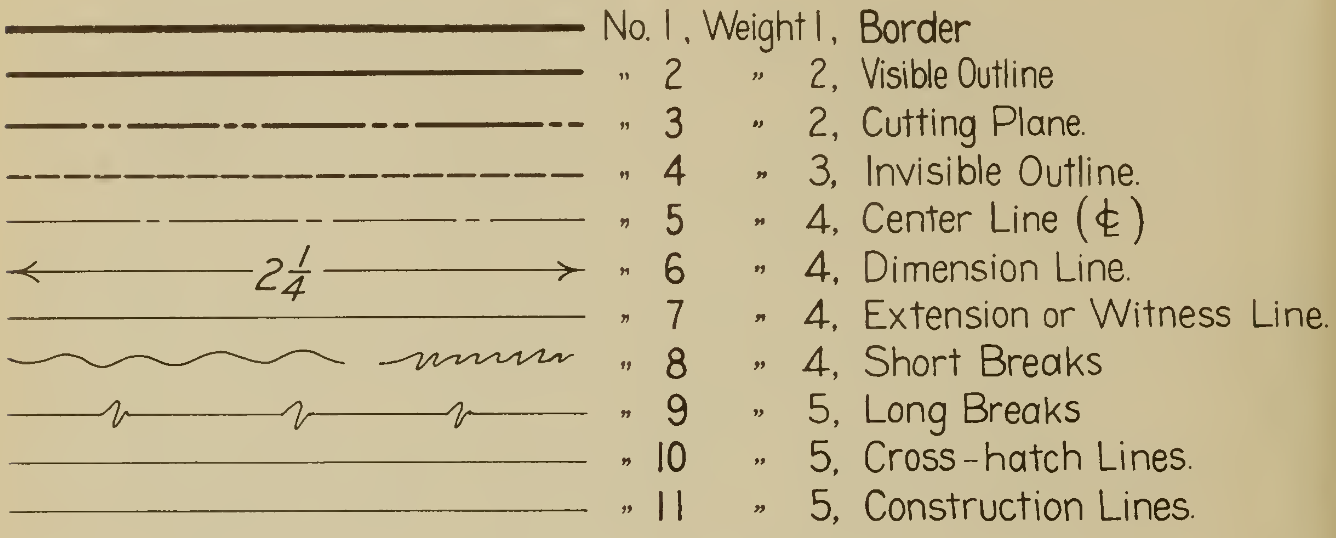


Figure 12-III. Conventional Lines

EXERCISES

17-III. The following figures may be used as exercises in teaching the use of drawing equipment; or if the instructor wishes, he may assign exercises for this purpose from Chapter IV, "Geometrical Element of Structures." The plate layout (A), (B), or (D), Figure 2-I, will be suitable for the assigned exercises.

The title of each drawing is the exercise number, group numbers, and chapter numbers, i.e., Ex. 4, Gr. 2, Ch. III, executed as illustrated in Figure 2-I, and placed 1/4-inch from the nearest line of the drawing.

PROCEDURE. Divide the sheet into equal rectangles of sufficient size to permit 4-inch squares to be drawn in them, the number of rectangles to equal the number of assigned exercises. Construct a 4-inch square in the center of each rectangle. Draw the assigned exercise in the square and letter the title as described above. When the exercise is finished, the square and the rectangle should be erased, unless these lines form a part of the drawing. The figures, including the dimensions, lettering, and descriptive matter, should be reproduced as shown. Study the instructions carefully and then draw the objects with neat, sharp, light, pencil lines. Have the pencil work checked and then ink the plate.

Group 1-III. Geometrical Studies

1. Figure 13-III on the following page. Divide AB into nine equal parts with the dividers. Through each point draw one line parallel to CB and another line parallel to BD by using a triangle and a straightedge. Complete the figure.
2. Figure 14-III on the following page. Lay off sixteen 1/4-inch squares on BA, from B toward A. Angle BAC = 45°. AC = 3 in. Draw parallel and perpendicular lines by combinations of the triangles and straightedge, then draw straight lines from F to the several points along line DE as shown.
3. Figure 15-III on the following page. Divide the square equally with the horizontal line AB. Point C is in the center of the square. Lay off the following angles as shown by using the triangles and

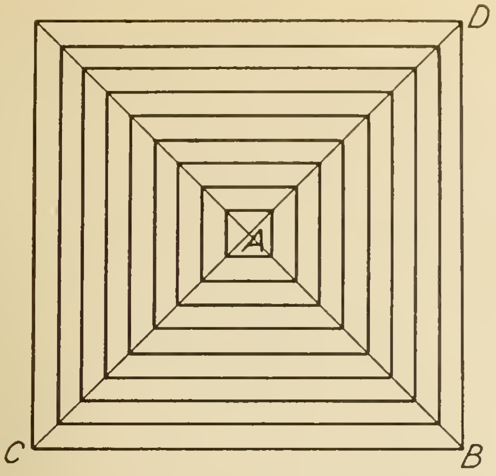


Figure 13-III

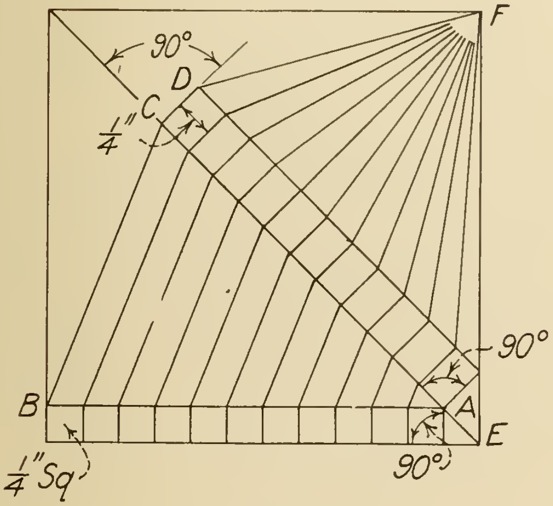


Figure 14-III

straightedge: ACI = 30°, ACK = 90°, ACL = 105°, ACH = 15°, ACG = 45°, ACF = 75°, ACE = 90°, ACD = 105°. By means of the dividers, divide lines CL and CD into 5 equal parts and complete the figure.

4. Figure 16-III. Draw a 4-inch circle. Divide the circumference into 5 equal parts, using the dividers. Draw a 5-pointed star. Draw the inner circle as shown.
5. Figure 17-III on the following page. Draw a 4-inch sphere and shade it as indicated. The point halfway between the center and circumference of the circle (on a 45° radius) is the center of concentric circles. Be careful not to dig deep holes into the paper. A center tack should be used.

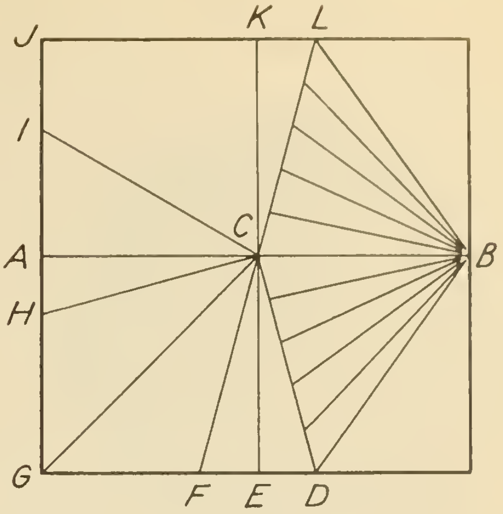


Figure 15-III

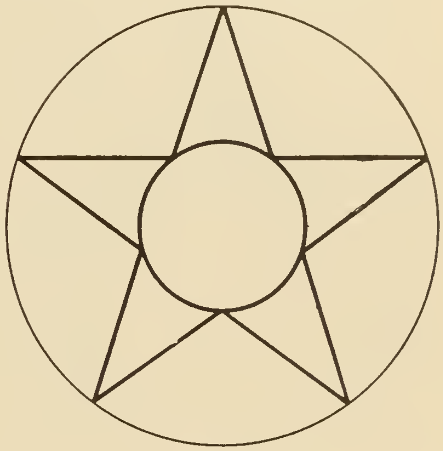


Figure 16-III

6. Figure 18-III on the following page. Locate point A on the vertical center line (L) as shown. Draw the equilateral triangle ABC. A part of the construction will have to be located by inspection. Point D is halfway between points A and E. Do not ink the square.
7. Figure 19-III on the following page. Lay out the square and draw the tangent arcs

as shown. Care should be used to make the arcs come tangent. Do not ink the square.

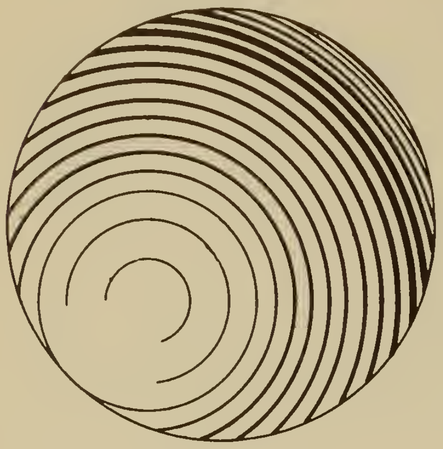


Figure 17-III

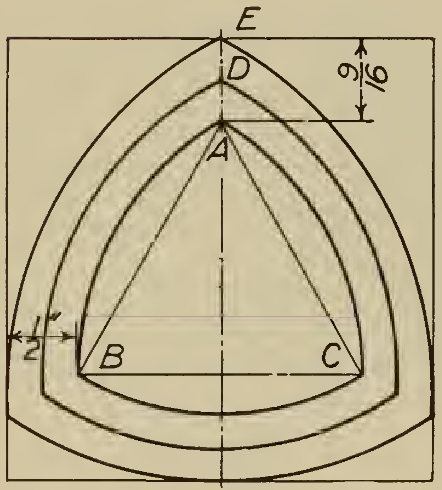


Figure 18-III

8. Figure 20-III. Lay out a 4-inch square and draw a one-inch equilateral triangle 1-2-3 as shown. Complete the object. Do not ink the square. R = 1 3/8; $R_1$=1 3/16. Distances 4-5 = 7/16; 5-6 = 1/4.

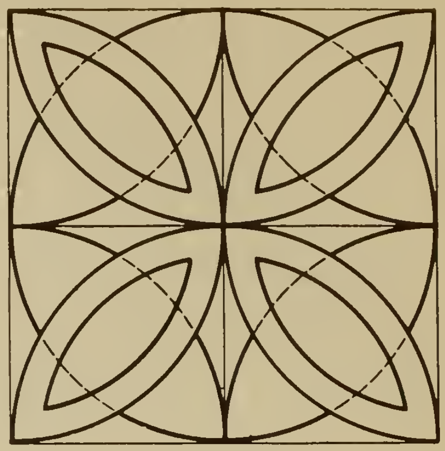


Figure 19-III

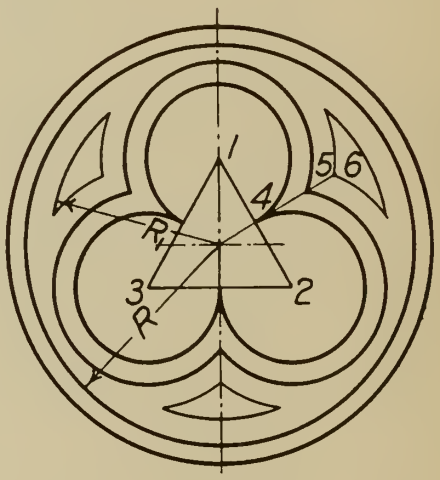


Figure 20-III

Group 2-III. Some Practical Application

1. Figure 21-III on the following page. Reproduce the roof trusses as shown, using approximately the same proportions used in the original drawings.
2. Figure 22-III on the following page. Same as exercise 1, but use Figure 22-III.
3. Figure 23-III on the following page. Reproduce the bridge trusses as shown.

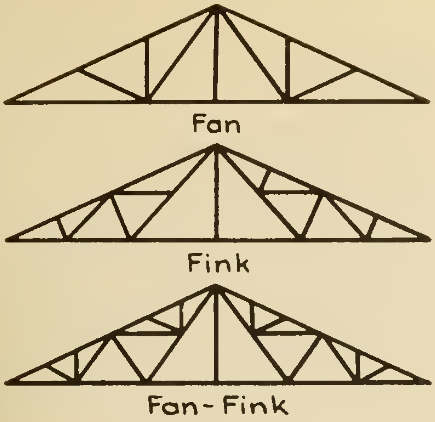


Figure 21-III. Roof Truss Diagrams

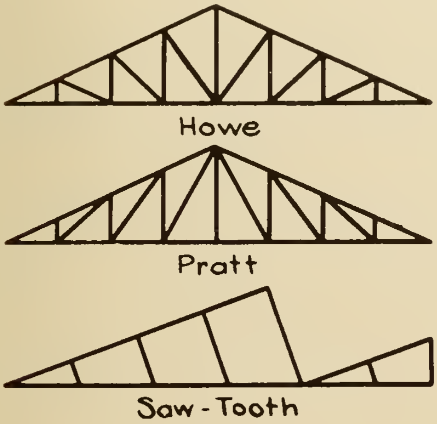


Figure 22-III. Roof Truss Diagrams

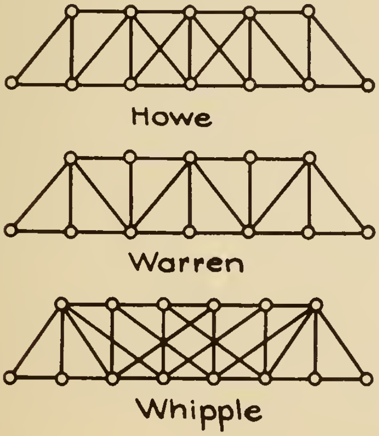


Figure 23-III. Bridge Trusses

Use 3/32 D circles. Keep approximately the same proportions used in the original drawings.

4. Figure 24-III. Same as exercise 3, but use Figure 24-III.

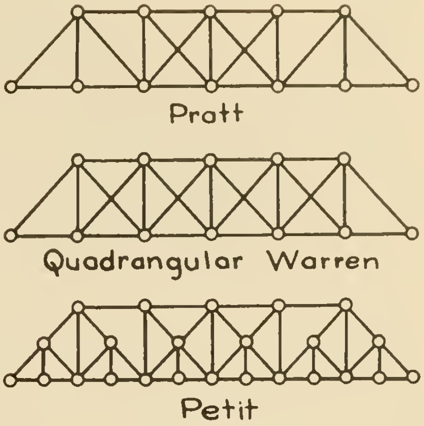


Figure 24-III. Bridge Trusses

5-8. Figures 25-III - 28-III. Each figure represents a separate exercise. Reproduce the objects as shown.

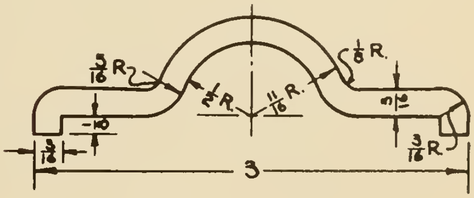


Figure 25-III. Cap

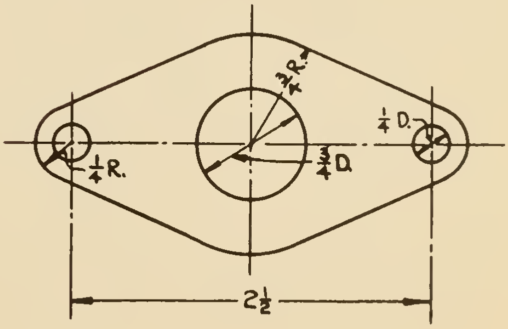


Figure 26-III. Gasket

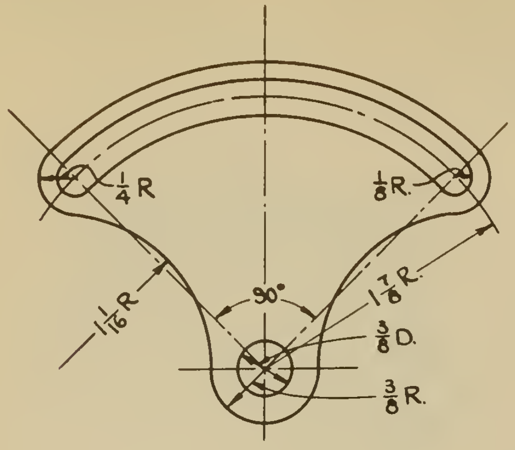


Figure 27-III. Ratchet

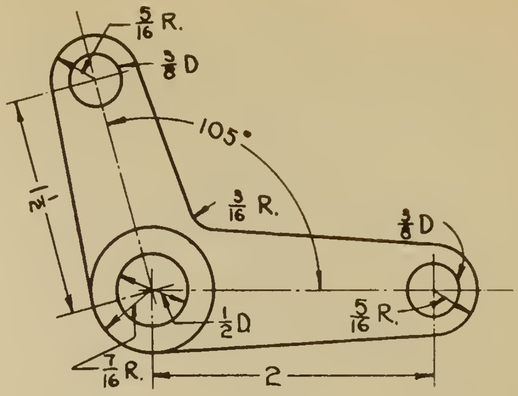


Figure 28-III. Bell Crank

# CHAPTER IV

## GEOMETRICAL ELEMENTS OF STRUCTURES

1-IV. The practical application of geometry, i.e., the geometry involved in constructing or assembling objects, is the alphabet of engineering drawing. It is, therefore, assumed that the student has mastered the fundamentals of geometry. For this reason, the more elementary problems in geometrical construction are omitted and only the ones given that are emphasized in drawing or sufficiently advanced to require a place in this chapter. The student should become familiar with all of the problems described here.

The geometrical elements of a structure are (1) points, (2) lines, and (3) surfaces. All geometrical shapes are composed of these elements, as illustrated in Figures 1-IV (page 36) and 2-XII (page 123). The student should study the illustrations in detail and refer to them frequently until he is able to visualize the various structures to be drawn.

2-IV. To Divide a Line. (1) With instruments: Use the method described in Article 8-III. (2) Geometrically: Use the method illustrated in Figures 13-III and 14-III. In Figure 13-III, the diagonals are all divided into the ratio of 1 to 1 (1 : 1). The divisions are all equal because the angles are all equal, and the diagonals are equal. Line AB in Figure 14-III is divided into 11 divisions. B and C are connected, and succeeding lines are drawn parallel. AC is divided into the same ratio that AB is divided into, regardless of the angle BAC or the length of AC.

3-IV. To Transfer a Polygon. Any plane figure can be transferred from one position to another and might even be revolved in position by the method of dividing the figure into triangles illustrated in Figure 2-IV, and described as follows: Draw $A_1B_1$ = AB but making an angle of 75° with the horizontal instead of 60°. With a radius equal to AC sweep an arc with center at $A_1$. With a radius equal to BC sweep an arc with center at $B_1$. The intersection of the two arcs will locate $C_1$. To locate point $D_1$ proceed as before, using AD as a radius, center at $A_1$, and CD as a radius, center at $C_1$. Distance BD might be used as a radius, center at $B_1$, instead of using CD with center at $C_1$. In case an error is made in locating $C_1$, the latter method will prevent that error from entering into the location of $D_1$. The former method would involve the error in the location of $D_1$. Point $E_1$ is located similarly.

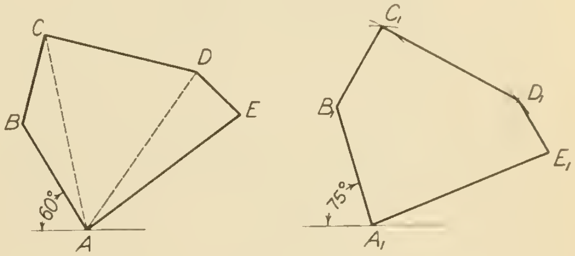


**Figure 2-IV. To Transfer a Polygon**

4-IV. Pentagon. (1) With instruments: Draw the circumscribed circle. Divide the arc of the circle into five equal divisions, Article 8-III. Connect the points. (2) Geometrically: Draw the circumscribed circle, Figure 3-IV. Line MN is the perpendicular bisector of AC. With E as a center, draw the arc from D cutting AB at F. With D as a center, draw the arc through F cutting the circle at G. Line GD is one side of the pentagon.

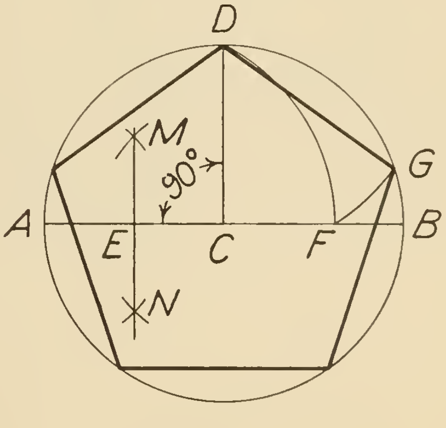


**Figure 3-IV. Pentagon**

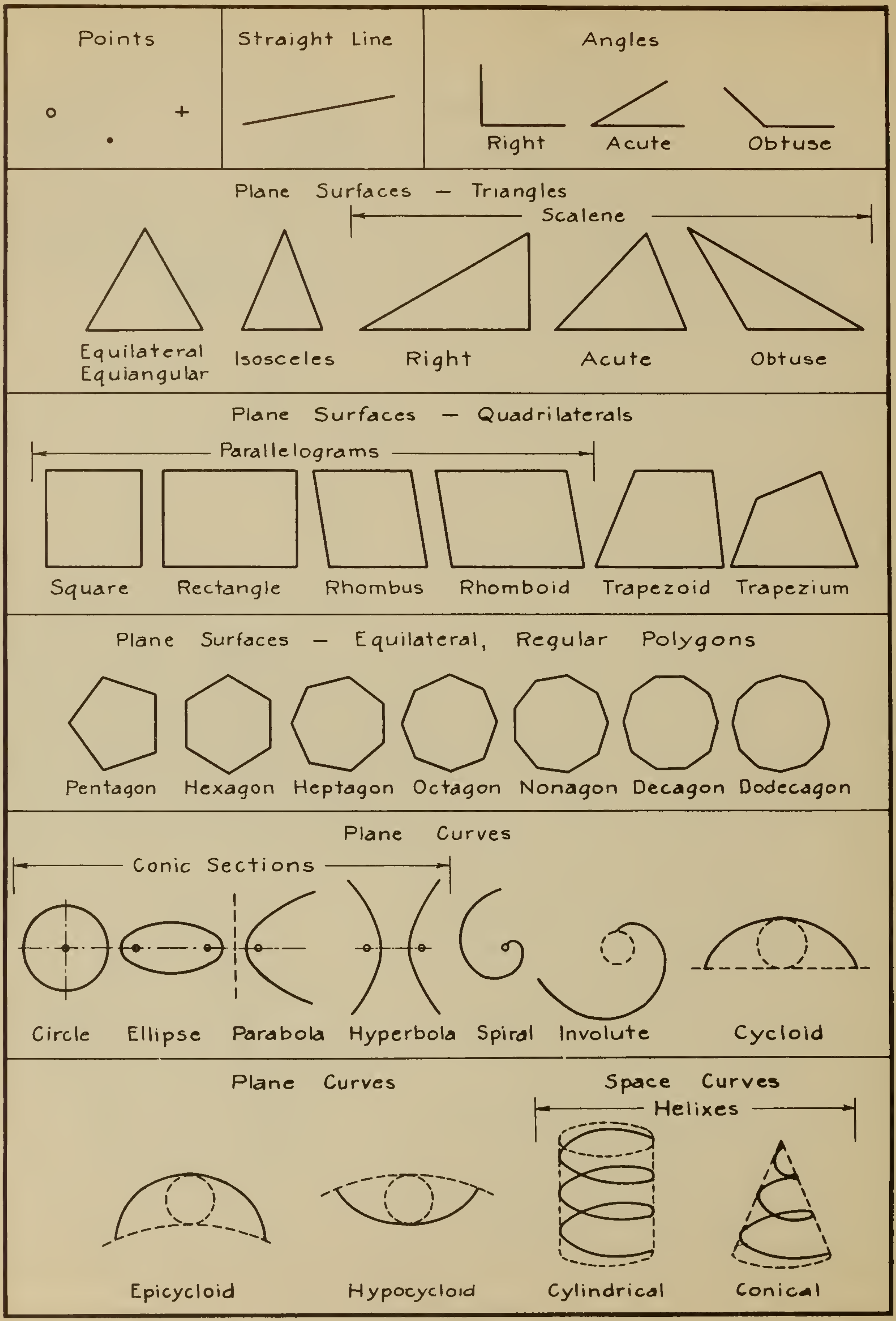


Figure 1-IV. Geometrical Elements of Structures

5-IV. Hexagon. (1) Across corners: Draw a line equal to the distance across corners, AB, Figure 4-IV. Draw a circle with AB as a diameter. With the same radius and centers at A and B, sweep the arcs cutting the circles at D E M and N. Connect the points as shown.

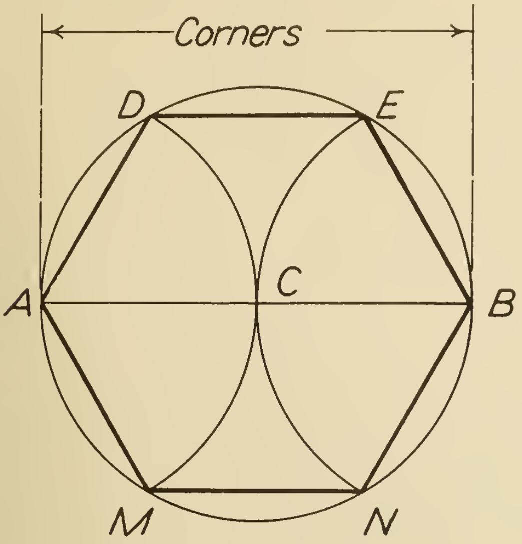


Figure 4-IV. Hexagon

(2) Across flats: With the distance across flats as a diameter, construct a circle with center at O, Figure 5-IV. Draw the horizontal diameter, AB, and the vertical diameter CD. Draw tangents at C and D. Construct the four tangents making an angle of $60^\circ$ with AB, as shown.

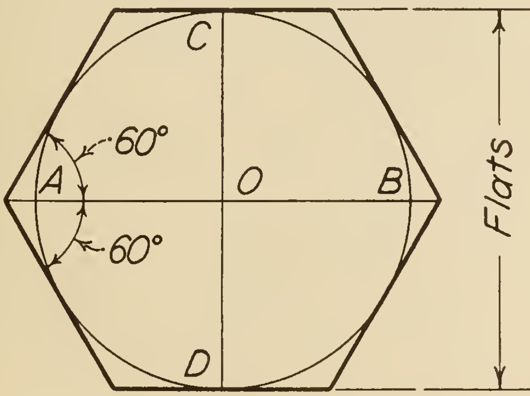


Figure 5-IV. Hexagon

(3) Triangle combination: Lay off a horizontal line, AB, equal to the distance across corners, Figure 6-IV. Lay off the various lines from A and B, making angles with AB as shown. Lines CD and OP are parallel to AB.

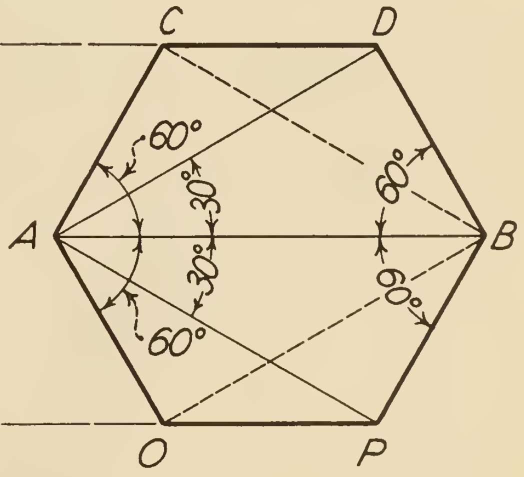


Figure 6-IV. Hexagon

6-IV. Octagon. (1) Construct a square with sides equal to the distance across flats of the octagon, Figure 7-IV. With A B C and D as centers sweep arcs with radii equal to half the diagonal AC, i.e., Radius = AO. Points where the arcs cut the sides of the square will locate the corners of the octagon.

(2) When the distance across corners is given, draw the circumscribed circle. Divide the circle into eight equal arcs as explained in Article 8-III. Connect these eight points.

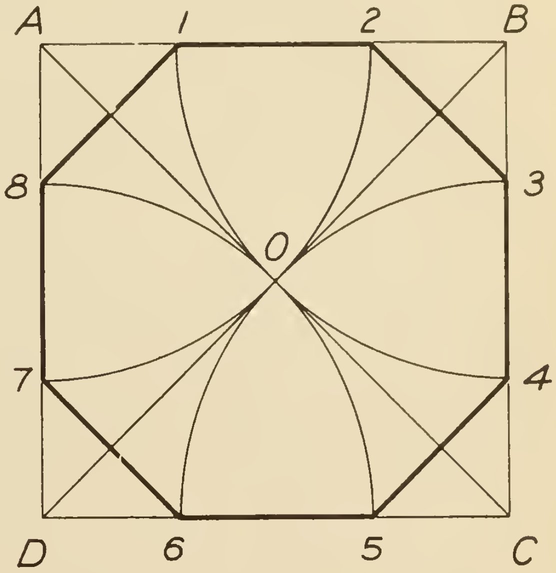


Figure 7-IV. Octagon

## PLANE CURVES

7-IV. Tangent Arcs. Arc centers and tangent points should always be marked in pencil and left on the drawing until after the inking or tracing has been finished.

(1) Arc connecting two straight lines: Draw two lines parallel to the two given straight lines at a distance R from the two given lines, Figure 11-III, (A), (B), and (C). The center of the arc will be at the intersection of the two constructed lines. Locate the tangent points and with radius R, draw the arc.

(2) Line tangent to a circle at point P: Draw the arc through point P. At P, construct a line perpendicular to the radius, Figure 11-III, (D).

(3) Arc tangent to an arc at point O: Draw a radius of the given arc through point O. On the radius extended through O, lay off a distance OC equal to the radius of the required arc, $R_1$. C is the required center, Figure 11-III, (E).

(4) Arc with radius R tangent to a straight line and tangent to an arc of radius $R_1$, Figure 8-IV (A): With radius R draw a line parallel to the given line. With a radius R + $R_1$ and center at the center of the given arc, sweep an arc that will cut the constructed parallel line at C. Point C is the center of the required arc.

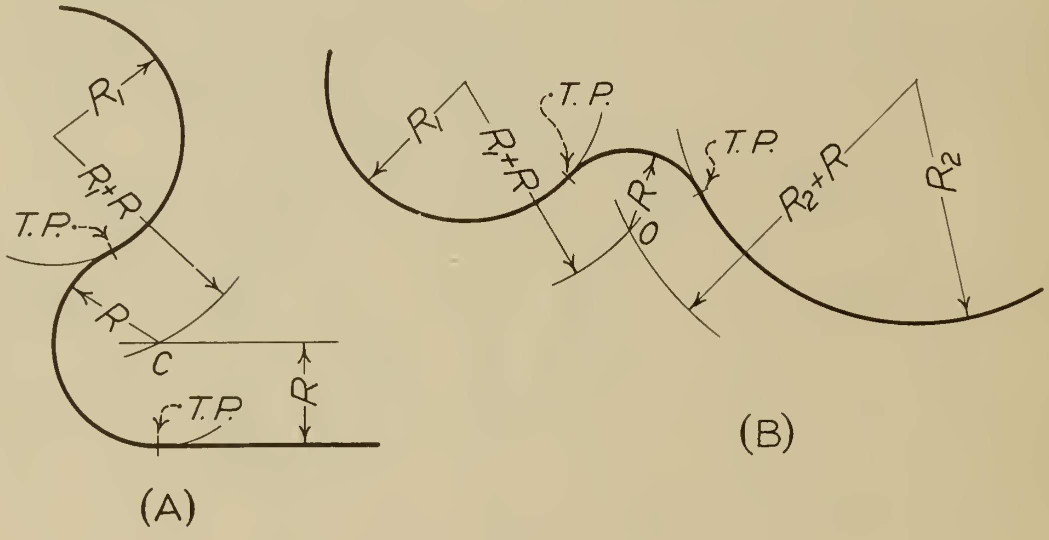


Figure 8-IV. Tangent Arcs

(5) Connect two given arcs of radius $R_1$ and $R_2$ with a tangent arc of radius R, Figure 8-IV (B): With a radius R + $R_1$ sweep an arc as shown. With a radius R + $R_2$ sweep an arc cutting the first arc at O. Point O is the center of the required arc.

(6) Reverse curve, Figure 9-IV: Given two straight lines AB and EF to be connected by the reverse curve BDE. Connect B and E.

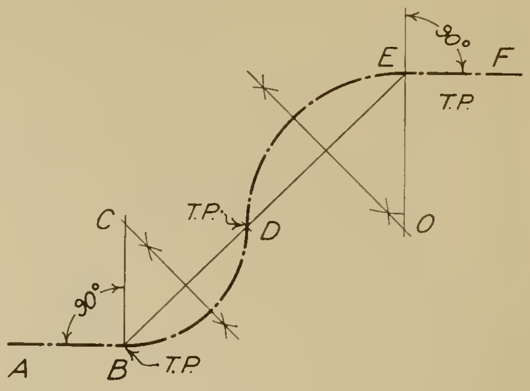


Figure 9-IV. Reverse Curve

BD is selected as a convenient distance on BE. At B erect a perpendicular to AB. Erect the perpendicular bisector of BD. The two perpendiculars intersect at C, the center of one of the arcs. Point O, the center for the second arc is found in a similar manner.

8-IV. To Lay off on a Tangent the Length of a Given Arc: (1) When the arc AB subtends an angle at C of 60° or less, Figure 10-IV (A) on the following page: At A, draw the tangent AD and the chord AB produced. Lay off AP equal to half of AB. With P as a center and radius equal to PB sweep an arc through B cutting the tangent at O. Distance AO is approximately equal to the length of arc AB.

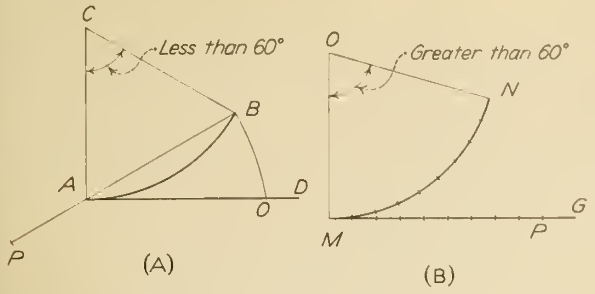


Figure 10-IV. Length of ARC

(2) When the arc MN subtends an angle at O greater than $60^{\circ}$, Figure 56 (B): Draw the tangent MG. Set the dividers to a very small space and make an even number of divisions on the arc MN. Make the same number of equal divisions on MG, ending at P. Distance MP is approximately equal to the length of arc MN.

(3) To compute the length of arc MN, Figure 10-IV (B): Angle MON in degrees $\div$ 360 degrees = MN $\div 2\pi R$, where R is equal to the radius of the arc; or $MN = 2\pi R \frac{(MON)^{\circ}}{(360)^{\circ}}$.

9-IV. Conic Sections. The four conic sections are the circle, ellipse, parabola, and hyperbola, Figure 11-IV. They are cut from a right circular cone by a plane making various angles with the base of the cone as follows: (1) the circle. Plane is parallel to the base. (2) the ellipse. Plane makes a smaller angle with the base than the elements do. (3) the parabola. Plane makes the same angle with the base that the elements make. (4) the hyperbola. Plane makes a greater angle with the base than the elements do.

It should be noticed that in cutting the four conic sections, as shown, the plane is rotated from a horizontal to a vertical position, i.e., the cutting plane is first parallel to the base, whereas the last position is perpendicular to the base.

10-IV. Circle. The circle is a plane curve generated by a point which moves so that its distance from a fixed point, called the center, remains constant. The constant distance is the radius, R, of the circle. The size of a circle is usually specified by giving the diameter, D. The analytical equation of the circle is $x^2 + y^2 = R^2$. The variables x and y are measured on axes constructed at right angles to each other.

11-IV. Ellipse. An ellipse is a plane curve generated by a point P which moves so that the sum of the two distances from fixed points called the foci, $F_1$ and $F_2$, Figure 12-IV, remains constant. The constant distance is equal to the major axis, AB. That is $F_1P + F_2P = AB$.

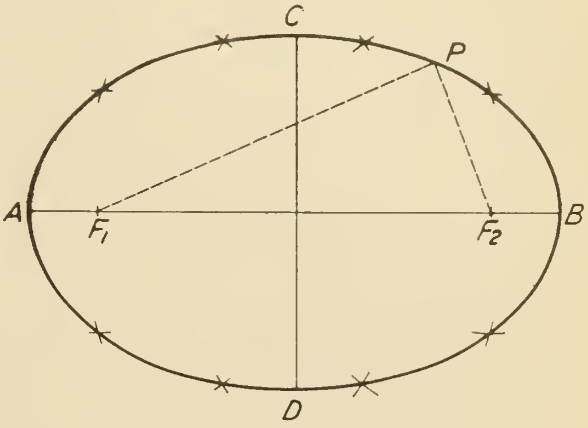


Figure 12-IV. Ellipse, Foci Method

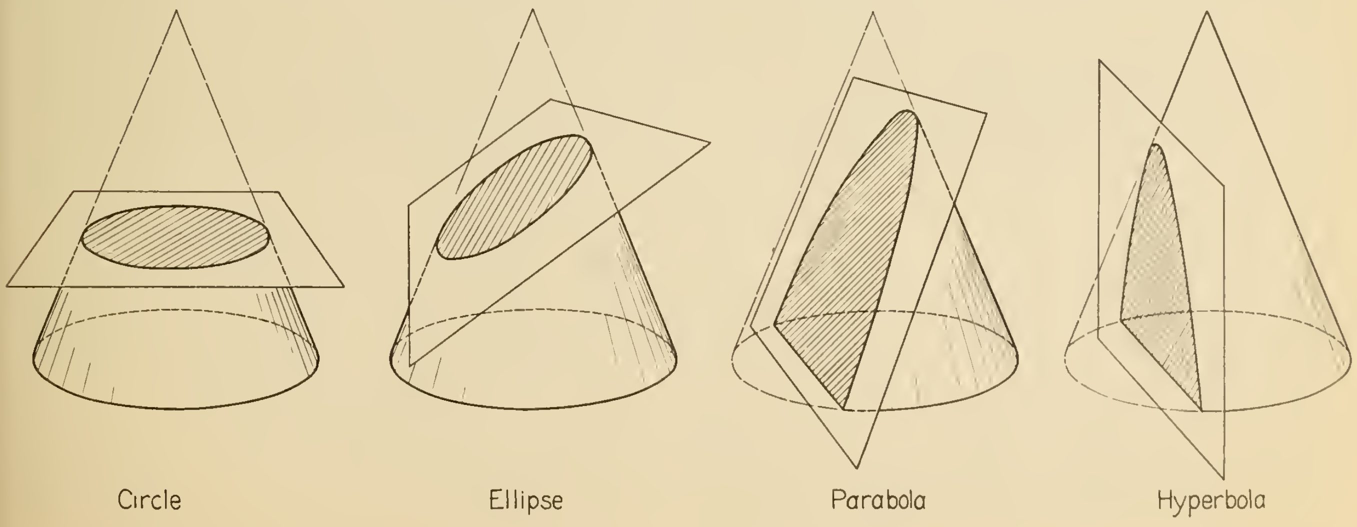

Circle
Ellipse
Parabola
Hyperbola

Figure 11-IV. Conic Sections

The ellipse is often used in engineering drawing. It represents a circle in oblique position. Occasionally elliptical beams, levers, spokes of wheels, and arches are built into engineering structures.

(1) Ellipse, foci method, Figure 12-IV: Given the major axis AB and the minor axis CD. Locate the foci, $F_1$ and $F_2$, by taking half the major axis, 1/2 AB, as a radius, C or D as a center, and sweeping arcs cutting AB at $F_1$ and $F_2$. Take a convenient distance as a radius, $F_1P$, but shorter than AB. Set up at $F_1$ and sweep an arc. Take as a radius the difference between AB and the radius $F_1P$, i.e., $F_2P$, and sweep an arc with $F_2$ as a center. The two arcs will intersect at a point P which is on the curve. Locate a sufficient number of points and connect these points by the use of the irregular curve, Article 12-III.

(2) Ellipse, trammel method, Figure 13-IV: Given the major axis AB and the minor axis CD. On the straight edge of a hard strip of paper, lay off half the major axis, xz. From point z lay off half the minor axis, yz. Place the strip so that x is always on the minor axis and y always on the major axis. Set a point at z. Shift the strip so that a convenient number of points are secured. Using the irregular curve, Article 12-III, connect the points.

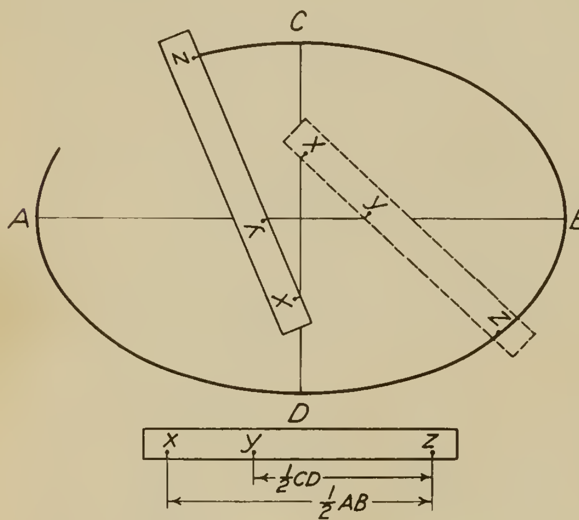


Figure 13-IV. Ellipse, Trammel Method

(3) Ellipse, conjugate diameters, Figure 14-IV: Given the conjugate diameters MN and RS, with the required angle between them, ROM. Construct the parallelogram as shown. Divide MO into any convenient number of equal parts, 1, 2, 3, etc. Divide MK into the same number of equal parts, numbering the points as shown. Through these points draw lines from R and S. The intersections of these lines will be points on the curve. Using the irregular curve, Article 12-III, draw the ellipse. The construction for only one quadrant is shown.

To locate the major axis, AB, and the minor axis, CD, draw a semicircle with radius equal to OS and center at O. Connect the point of intersection, P, of the circle and the ellipse, with R and S. The major and minor axes will be parallel to the chords PR and PS, respectively.

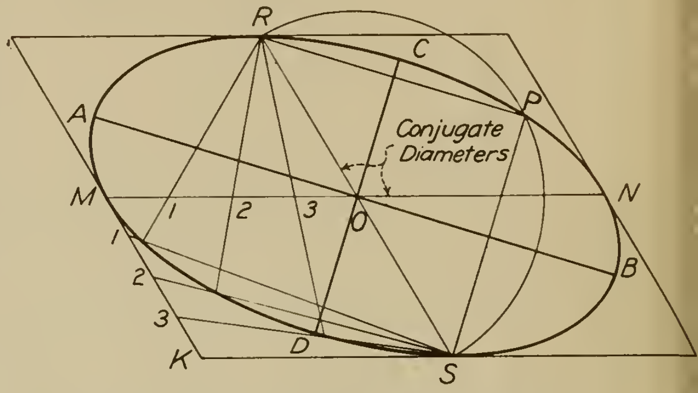


Figure 14-IV. Ellipse, Conjugate Diameters

(4) Ellipse, approximate method, Figure 15-IV: Given the major axis AB and the minor axis CD. Connect A and C. Lay off CP equal to the difference between half the major and half the minor axis, i.e., CP = 1/2 AB - 1/2 CD. Erect the perpendicular bisector of AP, and locate points M and S as shown. Lay off ON equal to OM. Draw SN. Locate R by making OR equal to OS. Complete the figure as shown. With centers at M, N, R, and S, draw in circular arcs which will approximate the ellipse. This method should not be used when drawing exceptionally large or small ellipses.

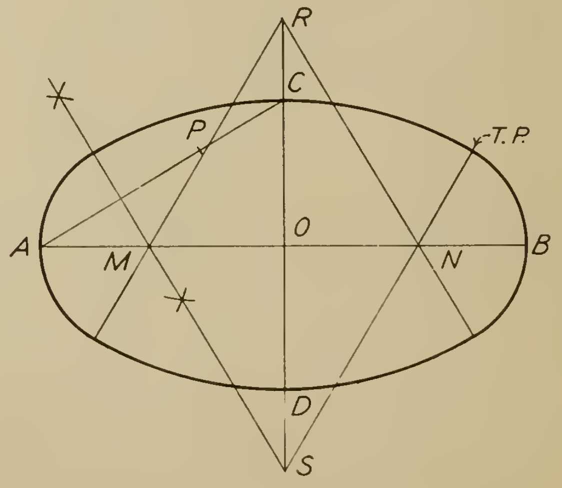


Figure 15-IV. Ellipse, Approximate Method

12-IV. Parabola. The parabola is a plane curve generated by a point which moves so that its distance from a fixed point called the focus, F, Figure 16-IV, is always equal to its distance from a fixed straight line, AB, called the directrix. Or, FP = PO. Also, CV = VF.

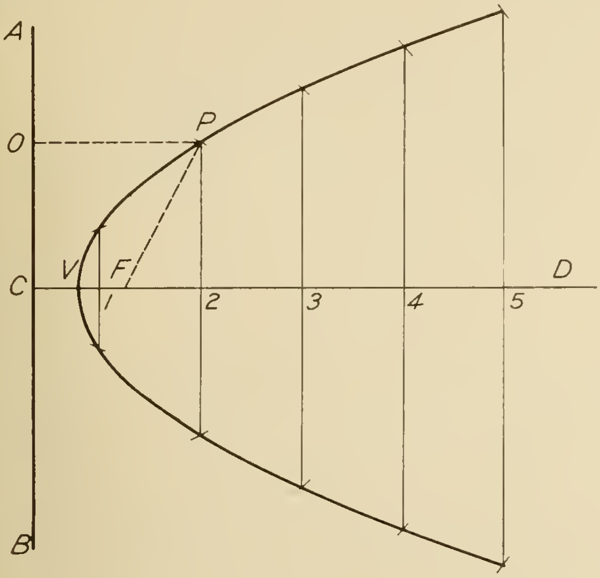


Figure 16-IV. Parabola

With a light fixed at F, a parabolic reflector will throw a prism of light rays straight ahead, i.e., parallel to the axis, CD. A parabolic beam will require the least amount of material when designed to carry a given load. Arches and roof sections are sometimes built parabolic.

To draw the parabola when the directrix, focus, and axis are given: Draw lines 1, 2, 3, etc., parallel to the directrix, AB, Figure 16-IV. Take the distance that line 3, for example, is from the directrix, use F as a center and sweep arcs cutting line 3 in two places. These points are on the parabola. In a similar manner locate two points on all lines. Draw a smoothe curve, Article 12-III, through all points so located. The curve will be a parabola.

13-IV. Hyperbola. The hyperbola is a plane curve generated by a point which moves so that the difference of its distances from two fixed points, called the foci, $F_1$ and $F_2$, Figure 17-IV, is equal to a constant, AB. That is, $F_1P - F_2P = AB$. See definition for ellipse.

Certain warped surfaces, such as the hyperboloid of revolution and the hyperbolic paraboloid, will give hyperbolic sections when cut properly. Also, the curve which represents the relation between the volume and pressure of a perfect gas is an hyperbola.

To draw an hyperbola when the foci and common difference are given: Locate the foci, $F_1$ and $F_2$, Figure 17-IV. These points are on the axis. Erect the directrix, CD, which is the perpendicular bisector of $F_1F_2$. From CD, lay off on the axis, in either direction, one-half the common difference. This will locate A and B. Take as a radius any distance greater than $F_1B$, say $F_1P$. Using $F_1$ and $F_2$ as centers sweep four arcs. With a radius equal to $F_1P$ - AB and centers at $F_1$ and $F_2$ as before, sweep four more arcs intersecting the ones just constructed. The points of intersection will be points on the desired curves. The curve may be drawn as explained in Article 12-III.

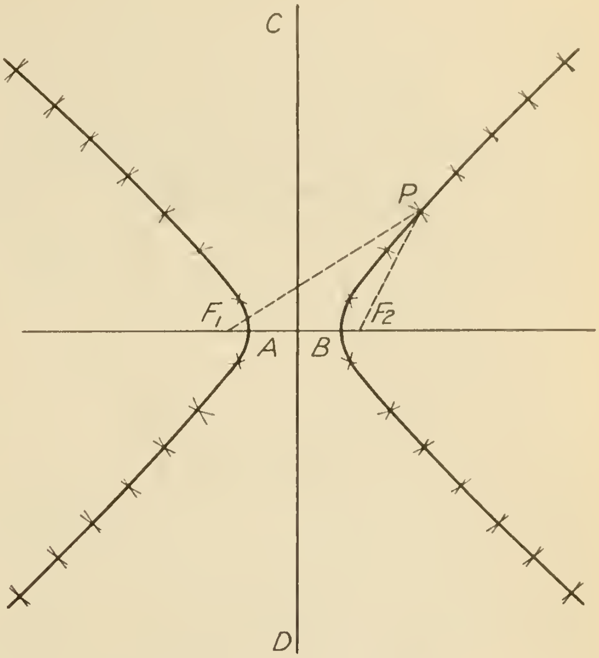


Figure 17-IV. Hyperbola

14-IV. Involute of a Circle. A point on a line will generate the plane curve called the involute of a circle when the line is unwrapped from around the director circle, if kept taut and therefore straight and tangent to the circle. A right-hand involute is shown in Figure 18-IV on the following page. An involute of a square is inserted.

Gear teeth are usually shaped to the curve of an involute, in which case the teeth will roll and not slide on each other, Figure 32-IV.

To draw an involute of a circle when the diameter of the director circle is given, Figure 18-IV: Divide the circle into a convenient number of equal parts, say 12. Compute the circumference of the circle and lay the distance off on a straight line, AB. Divide the line into the same number of divisions made of the circle, 12. Draw tangents to the circle at the points of division. Lay off on tangent 1 the distance 0-1 taken from the straight line. Lay off on tangent 2 the distance 0-2, etc., until the corresponding distances are all laid off on their respective tangents. Starting at 0, draw a smooth curve through the various points as outlined in Article 12-III, or with the compass using 1, 2, etc., as centers with radii equal to 1-0, 2-0, etc.

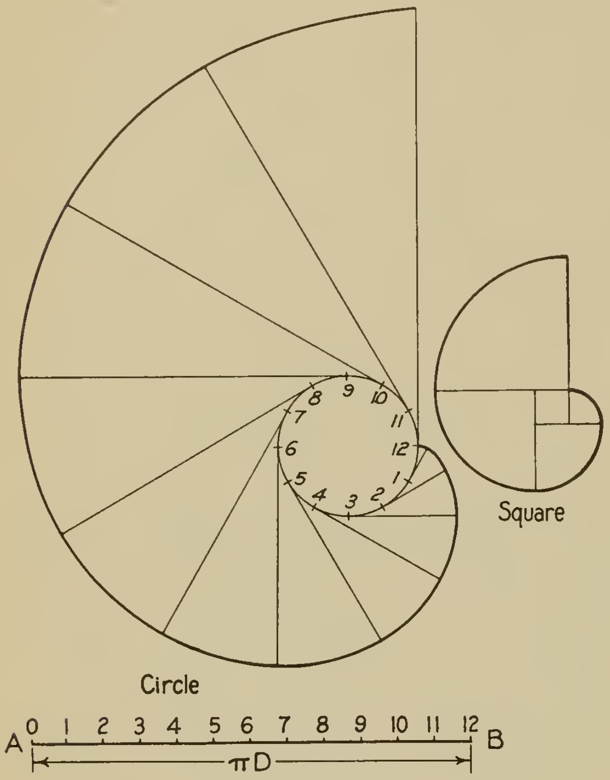


Figure 18-IV. The Involute

15-IV. Spiral of Archimedes. The spiral of Archimedes is a plane curve generated by a point revolving at a uniform rate of speed about a fixed point called the pole and at the same time moving at a uniform rate of speed away from the axis. Figure 19-IV shows the method of constructing a right-hand Archimedean spiral.

Threads cut on the face of a plate, as the threads of scroll chucks, and cams for the conversion of uniform rotary motion into uniform reciprocating motion, are shaped to the outline of the Archimedean spiral.

To draw the spiral of Archimedes, given the lead: One turn of a right-hand spiral is shown in Figure 19-IV. Lay off the lead on a straight line, AB, and divide the lead into a convenient number of equal parts, say 12. Draw the same number of equally spaced radial lines around the pole, or fixed point, that the lead was divided into, 12. On radius 1, lay off distance 0-1. On radius 2 lay off distance 0-2, etc., until the corresponding distances are all laid off on their respective radii. Starting at the pole, draw a smooth curve through all the points just located, as outlined in Article 12-III.

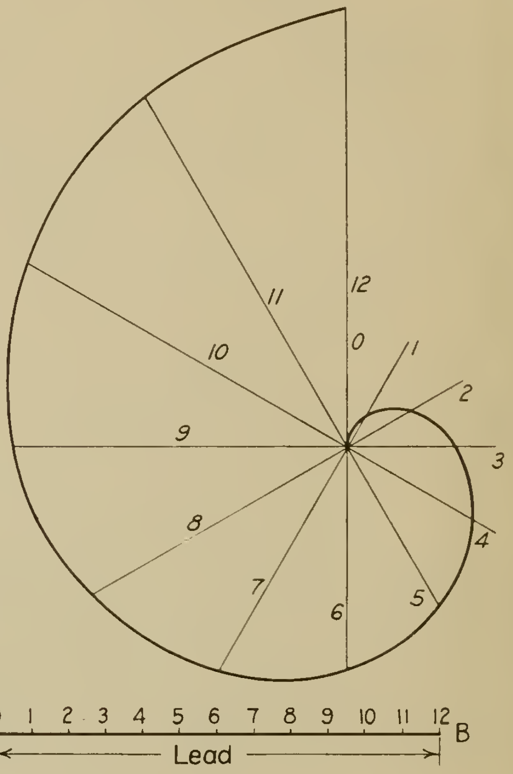


Figure 19-IV. Spiral of Archimedes

16-IV. The Cycloid. The cycloid is a plane curve generated by a fixed point on a circle which rolls on a straight line. It is used to a limited extent for the outline of gear teeth.

To draw a cycloid: Obtain the diameter of the rolling circle, Figure 20-IV on the following page, and compute the circumference. Lay this distance off on the straight line director, A to B. Divide the circle into a convenient number of equal parts. Divide the distance AB into the same number of equal parts. The generating point starts at A and comes back to the director again at B as the circle rolls along the straight line. Lay off centers on a horizontal line drawn through center of the rolling circle which will correspond to the divisions of AB. Draw horizontal lines, through the various divisions of the circle. With center at point 1, and radius equal to the radius of the circle, sweep an arc cutting horizontal line 1, as shown. Repeat and connect successive points until the curve comes to B and there reverses. The highest point of the curve is above center 8, a distance equal to the diameter of the circle.

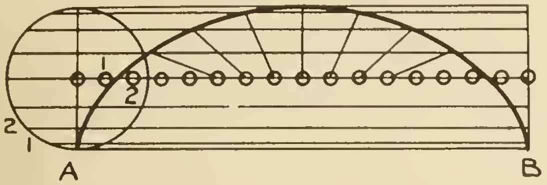


Figure 20-IV. The Cycloid

17-IV. Epicycloid. The epicycloid is a plane curve generated by a fixed point on a circle which rolls on the outside of another circle. It is used to a limited extent for the outline of gear teeth.

To draw an epicycloid: Obtain the diameters of the rolling circle and director circle, Figure 21-IV. Compute the circumference of the rolling circle. Lay this distance CD off on the arc of the director circle. Divide the rolling circle and the director arc into a convenient number of equal divisions. Draw radii through these dimensions as shown. Point C and center A lie on the same radius. Draw arcs through the various divisions of the rolling circle. With centers at the indicated points on arc AEB and with radii equal to the radius of the rolling circle, sweep arcs cutting the major arcs which are parallel to the director arc. Draw a smooth curve through the points thus located.

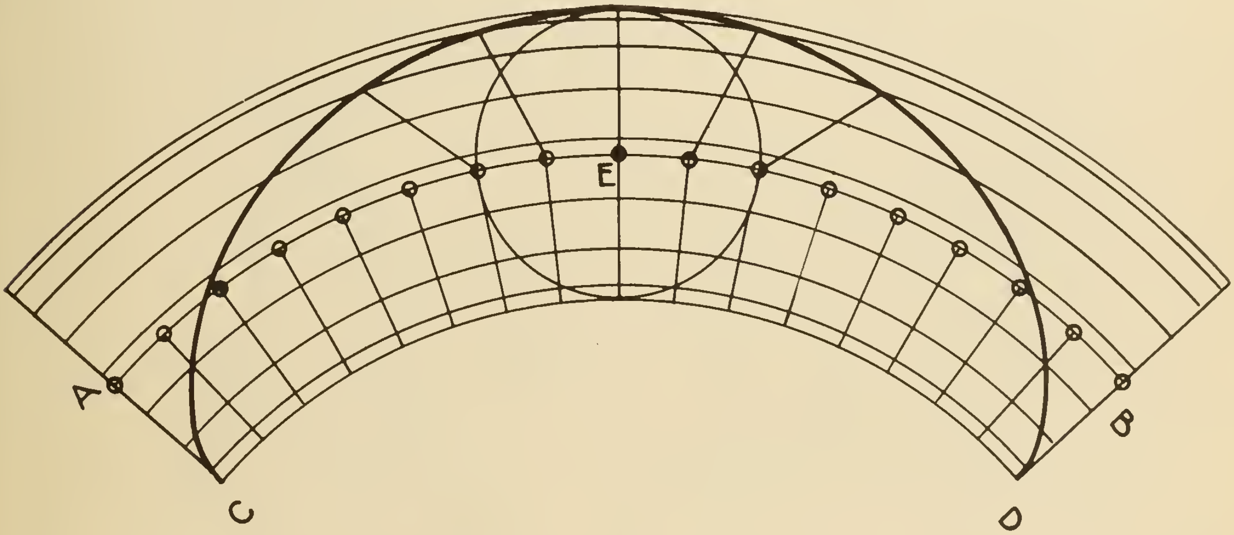


Figure 21-IV. The Epicycloid

18-IV. The Hypocycloid. The hypocycloid is a plane curve generated by a fixed point on a circle which rolls on the inside of another circle. It is used to a limited extent for the outline of gear teeth.

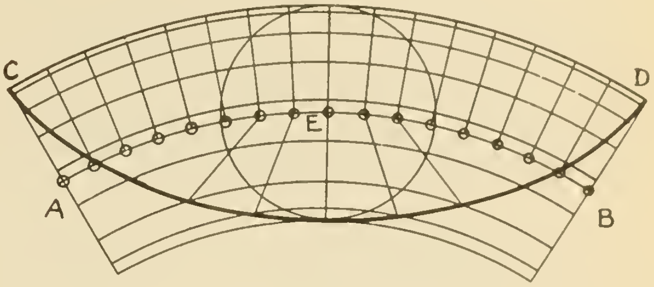


Figure 22-IV. The Hypocycloid

The hypocycloid, Figure 22-IV, is constructed in much the same manner as the epicycloid, the exception being that the rolling circle rolls on the inside and not the outside of the director arc.

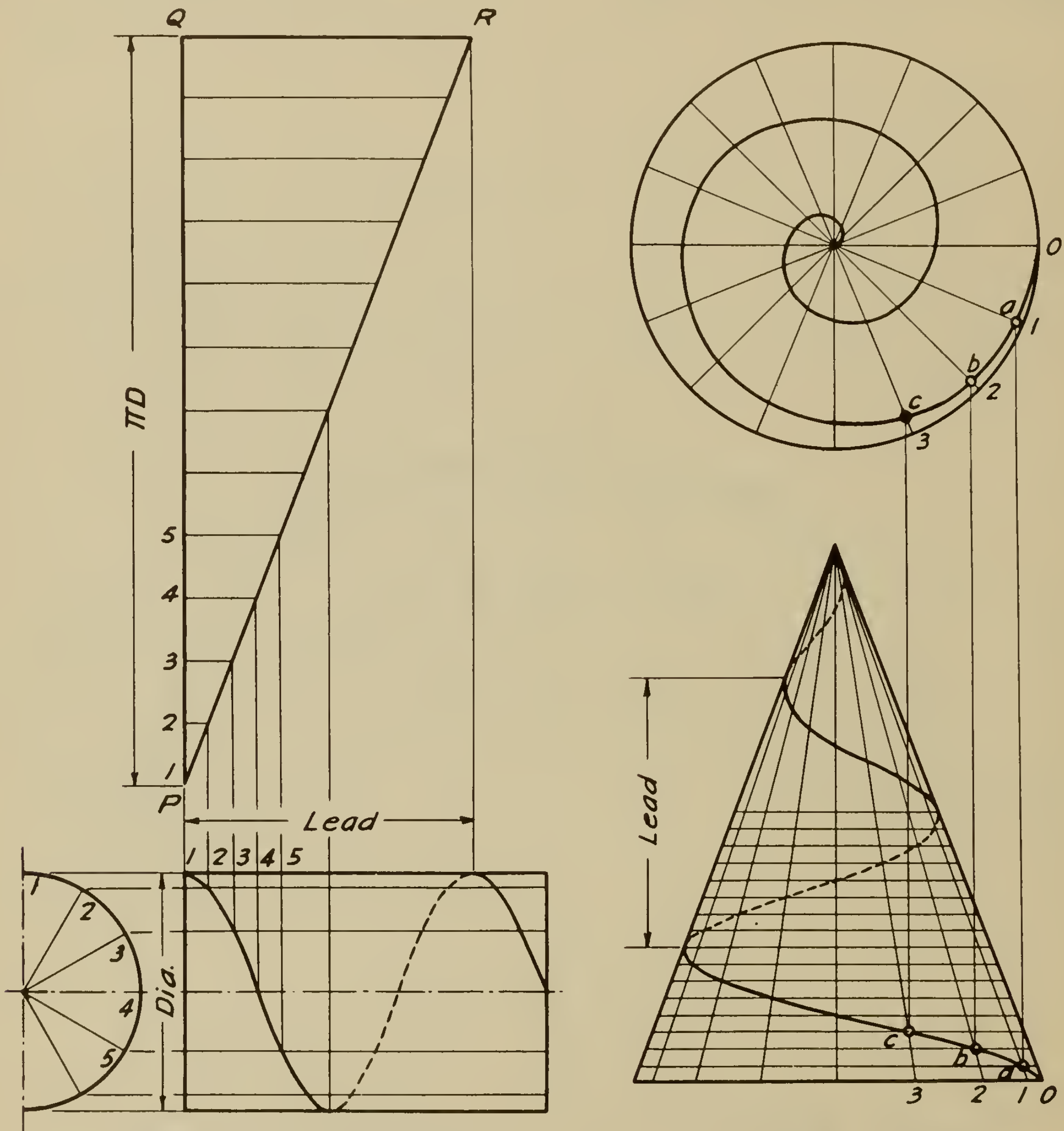
## SPACE CURVES

19-IV. Space Curves. A space curve is a curved line having no four consecutive points in a plane. It is continually changing from one plane to another and therefore cannot be completely represented in any one view. It will appear curved from every point of view. The most common illustrations are the helical curves. A study should be made of the illustrated classification of curved lines, Figure 1-IV.

20-IV. Helical Curves. The helix is a space curve generated by a point revolving at a uniform rate about an axis while moving uniformly in the direction of the axis. If the generating point remains at a constant distance from the axis, the curve generated will be a cylindrical helix, Figure 23-IV (A). If the generating point moves away from the axis at a uniform rate, the curve generated will be a conical helix. When the "helix" is specified, a cylindrical helix is understood.

A very common definition is thus stated: A helix is a space curve generated by a point moving uniformly along a straight line while the line revolves uniformly about a straight line axis. If the moving line revolves parallel to the axis, a cylindrical helix is generated. If the line intersects the axis at an acute angle, a conical helix is obtained. If the angle between the line and the axis is 90 degrees, the spiral of Archimedes, a plane curve, is generated.

The point of the tool in a lathe, while cutting a thread, generates a helix. The surface of the thread is a helicoid,



Right-hand Cylindrical
(A)

Left-hand Conical
(B)

Figure 23-IV. Helical Curves

Figure 2-XII (page 123). The distance advanced parallel to the axis by the generating point while making one revolution is called the lead. Threads on wood screws and the shape of some springs conform to the outline of a conical helix.

To draw a cylindrical helix, Figure 23-IV (A). In line with the base of the cylinder, lay out PQ equal to the circumference of a right section of the cylinder. At one end, erect a perpendicular line, RQ. Lay off the lead on RQ. Complete the right-angle triangle. Divide the circular section of the cylinder and line PQ into a convenient number of equal parts. Only five points are here shown. Intersecting visual rays, drawn from the various division points, will locate points on the curve. Hypotenuse PR is equal in length to one turn of the helix. The slope of PR is equal to the slope of the tangent to the helix drawn at point 4. A considerable saving in space for exercises will be effected if πD ÷ 2 and Lead ÷ 2 are used instead of πD and Lead.

To draw a conical helix, Figure 23-IV (B). Lay off the lead parallel to the axis, as shown. Draw a convenient number of elements. Divide the lead into as many parts as there are elements. Draw horizontal slicing planes through the divisions just made. The intersection of slicing planes o-a-b-c- etc., with elements 0-1-2-3- etc., will locate points on the desired curve.

It should be noticed that the top view is the spiral of Archimedes. The lead being constant, scroll threads can be laid out to conform to such a curve.

## EXERCISES

21-IV. A space 5 1/2 x 5 1/2 will be large enough for each of the following exercises.

It is essential that the student be accurate in taking measurements, in laying out these measurements, and in his drafting if he expects to obtain accurate results.

PROCEDURE:

1. Draw light pencil lines with a well-sharpened drawing pencil.
2. Locate points at the intersection of pencil lines or by pricking holes in the paper with a needle point.
3. Refrain from jabbing holes in the paper with a pencil or a blunt instrument.

### Group 1-IV. Some Common Geometrical Shapes

1. Scale 1 1/2" = 1". Two spaces will be required for this problem. In the first space construct the polygon of Figure 24-IV as indicated. AB is horizontal. Lay off all angles by combinations of the triangles and T-square. Lines BC, CD, and EF all make angles with horizontal lines as indicated. DE is a vertical line, and FA closes the polygon.

   To transfer a polygon, Figure 24-IV: In the lower part of the second space, draw line AB so that point B will be revolved in a clockwise direction and so that AB will make an angle of 15° above the horizontal, A lying in the horizontal. Now transfer the polygon of this problem onto line AB so that points A and B coincide. See Figure 2-IV (page 35).

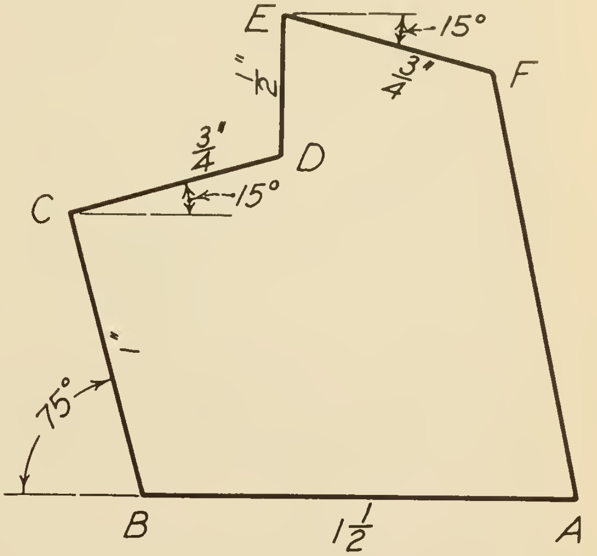


Figure 24-IV. To Transfer a Polygon. Problem 1

2. Transfer the polygon on the left in Figure 2-IV from the book to the plate. When transferring, revolve the polygon, as indicated in the figure on the right. Scale the length of the various lines in the figure and take measurements to the nearest 1/16". Then increase the measurements one and one-half times. Use combinations of the triangles and T-square in laying out any of the angles indicated.
3. Inscribe in a 4" circle a pentagon. See Figure 3-IV.
4. Inscribe in a 4" circle a hexagon as outlined in Figure 4-IV.
5. Circumscribe about a 3" circle a hexagon as outlined in Figure 5-IV.
6. Construct a hexagon similar to Figure 6-IV when the distance across flats is 3".
7. Construct an octagon similar to Figure 7-IV when the distance across flats is 4".
8. Draw a 2" horizontal line, AB, in the lower right-hand corner of the problem space. A is the tangent point. Draw two tangent

arcs, as illustrated in Figure 8-IV (A) when the center of the upper left-hand arc is on a 45° line through the center of the lower right-hand arc. R = 1" and $R_1$ = 1 1/2".

9. The center of radius $R_2$, Figure 8-IV (B), is in the lower left-hand corner of the problem space. The center of the radius $R_1$ is on a 30° line through the center of $R_2$. The two centers are 2 1/2" apart. $R_1$ = 1 1/2" and $R_2$ = 3/4". Draw a connecting tangent arc, R = 1/2".
10. Draw the center line ABDEF, Figure 9-IV. On this center line construct a 5/8" hollow rod. Show the ends broken as illustrated in the Appendix, broken sections. Line EF is 2 1/4" above AB. Point E is 1 3/4" to the right of B. Line AB = EF = 3/4". Line BD = 1".
11. With a 3" R, sweep an arc with center in the upper left-hand corner of the problem space, Figure 10-IV. The arc is subtended by an angle of 75°. (Use the combination of triangles and T-square to draw the angle.) Show graphically on a tangent line the length of the arc just constructed.
12. Same as Problem 11, except the angle subtending the arc is 30°.
13. Given: Major axis = 3 1/4". Minor axis = 2 1/2". Construct an ellipse as illustrated in Figure 12-IV. Check by the trammel method, Figure 13-IV. Any discrepancy between the two curves should be shown by a dotted line.
14. With the major and minor axis given in Problem 13, construct an ellipse by the trammel method.
15. By the conjugate diameter method, Figure 14-IV, construct an ellipse. Given MN = 3" and RS = 1 7/8". Angle NOR = 105°. (Lay out this angle by a combination of triangles and T-square.) Locate and label the major and minor axes and the conjugate diameters. Check by the trammel method, Figure 13-IV. Any discrepancy between the two curves should be shown by a dotted line.
16. Change Problem 15 by making angle NOR = 90° and draw the ellipse as indicated.
17. Given: Major axis = 3" and minor axis = 1 5/8". Construct an ellipse by the approximate method, Figure 15-IV.
18. Given: CF = 1" (The distance from the focus to the directrix). Draw a parabola. Let the curve extend 2 1/8" to the right of the focus, Figure 16-IV.
19. Given CV = 5/8". Draw a parabola. Draw the curve a distance of 1 3/4" to the right of the focus, Figure 16-IV.
20. The foci of an hyperbola are 1 3/4" apart, Figure 17-IV. The constant difference is 1". Draw the curve 1 1/4" past the foci on both sides.
21. Given AB = 5/8", Figure 17-IV. The constant $F_1F_2$ is 1". Draw the hyperbola 1 1/2" past the foci on both sides.
22. Draw a 1" circle well toward the top and center of the problem space. Draw a right-hand and a left-hand involute of a circle. Start the curves at the top of the circle and stop them where they intersect at the bottom. Figure 18-IV.
23. The pole of an Archimedean spiral is located near the center of the problem space. The lead is 1 1/4". Draw 1 3/4 turns of a right-hand spiral. See Figure 19-IV.
24. Change the spiral in Problem 23 to a "left-hand" curve and draw as indicated.
25. Draw three turns of a helix, diameter 2 3/4", lead 1".
26. Draw three turns of a conical helix, large diameter 3", small diameter 1 1/4", and lead 1". Use a double space.
27. Draw a cycloid using a 1 1/4" generating circle.
28. Draw an epicycloid using a 1 1/2" generating circle and a 2 3/4" lead circle.
29. Draw a hypocycloid using a 1 1/2" generating circle and a 4 1/4" lead circle.

Group 2-IV. Some Practical Applications

1. Scale 1/8 = 1' - 0". Using the given scale, draw the camel-back bridge truss of Figure 25-IV. Draw the complete span.

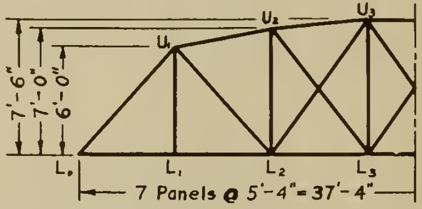


Figure 25-IV. Camel-back Truss

2. Horizontal scale 1" = 2500 feet per minute; vertical scale 1" = 25 pounds effective tension per inch of width. Using the scales

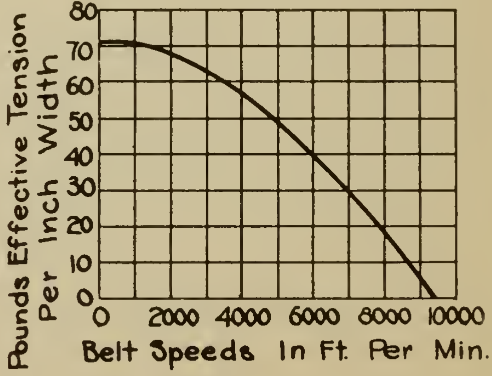


Figure 26-IV. Belt-Tension Diagram

given, reproduce the belt-tension diagram of Figure 26-IV.

3. Horizontal scale 1" = 10 years. Vertical scale 1" = 100 thousand population. Rule a 4" x 4" space similar to the ruling of Figure 26-IV and then locate the following points for population curves:

POPULATION TABLE GIVEN IN THOUSANDS

| Town | 1890 | 1900 | 1910 | 1920 | 1930 |
|---|---|---|---|---|---|
| Seattle | 42.8 | 80.7 | 237.2 | 315.3 | 365.6 |
| Portland | 46.4 | 90.4 | 207.2 | 258.3 | 301.8 |
| Salt Lake | 44.8 | 53.5 | 92.8 | 118.1 | 140.3 |
| Spokane | 19.9 | 36.8 | 104.4 | 104.4 | 115.5 |

Draw a smooth curve for each city through the points just located. First sketch the curves in very light pencil lines--free-hand. Make changes until the location is satisfactory. Then go over the free-hand curves with pencil and irregular curve to brighten the lines. Ink next, using the irregular curve and curve line ruling pen. Use the following line conventions for the various curves: Seattle solid, Portland dash-dot, Salt Lake dash-double-dot, Spokane dotted. A weight 2 line should be used.

4. Horizontal scale 1" = 0.02" per inch of strain. Vertical scale 1" = 10 thousand pounds per square inch of stress. Plot the stress-strain diagram for cold rolled steel, using the data listed in the following table:

TABLE FOR STRESS-STRAIN DIAGRAM

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Stress | 60M | 70M | 75M | 80M | 82M | 84M | 86M | 87M |
| Elongation | .0020 | .0024 | .0027 | .0034 | .0042 | .0058 | .0090 | .0160 |
| Stress | 87½M | 88M | 89M | 90M | 91M | 91½M | 91M | 90M |
| Elongation | .0200 | .0222 | .0267 | .0335 | .0440 | .0600 | .0700 | .0820 |

Stress is given in thousand pounds per square inch. Strain is the elongation (given in inches) per inch of bar length. Refer to EXERCISE 3 for procedure.

5. Scale 1 1/2" = 1". Draw the velocity diagram for a shaper crank as illustrated in Figure 27-IV. AB = 2". OD = 5/8". OC = 2". The ellipse and the parabola are tangent near points A and B. Directrix and focus are to be located by trial and error.

6. Scale 1 1/2" = 1' - 0". Draw the parabolic reflector of Figure 28-IV which shows the distribution of light rays. It will be noticed that some of the rays interfere with the "light pencil" which is parallel to the axis of the parabola. The light is located at the focus. The distance from the focus to where the parabola cuts the axis is 4".

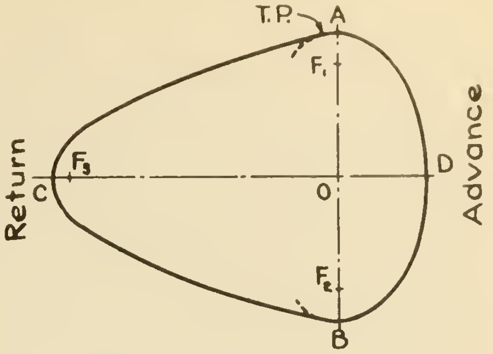


Figure 27-IV. Velocity Diagram for Shaper Crank

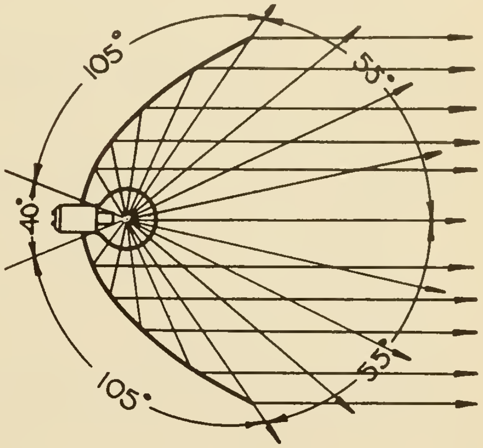


Figure 28-IV. Parabolic Reflector

7. Scale 1" = 200'. Draw a suspension bridge similar to the one shown in Figure 29-IV but with the following data: 14 panels at

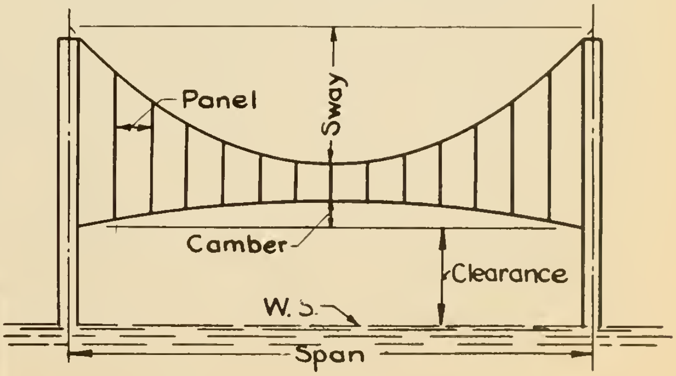


Figure 29-IV. Suspension Bridge

50' - 0" = 700' = span. Sway = 95'. Clearance = 90'. High water (H.W.) is 50' above low water (L.W.). Diameter of towers may be chosen to conform with the general symmetry of the bridge. Camber is 20' and is divided proportionately among the 14 panels with a distance of zero where the end panel joins the tower and the maximum distance of 15' where the middle panels join. A smooth curve is drawn through these points. The curve through the various points on the upper chord (upper ends of the panels) is an approximate parabola. With three points on the curve given, locate the focus F and the directrix by trial and error. Draw the approximate parabola.

8. Use any convenient scale. Draw the following theoretical steam card. The curves are hyperbolic. An engine has a piston stroke of 18", steam pressure 100 lb., cut off at 1/5 of stroke, compression at 3/5 return stroke, and cylinder clearance of 0.10. See Figure 30-IV.

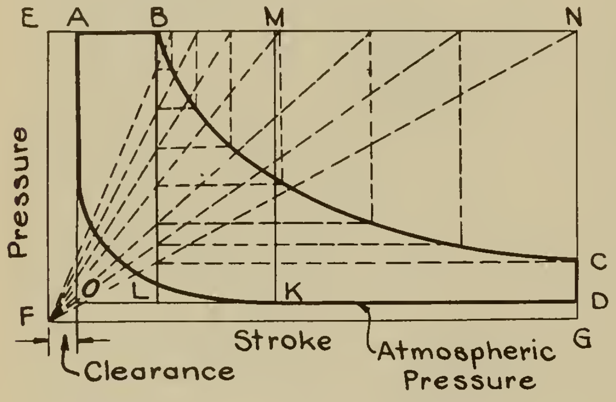


Figure 30-IV. Theoretical Steam Card

(1) Draw the rectangle ANDO, making AN 18" and EF 100 lb., both drawn to scale.
(2) Draw the rectangle ENGF, so that EA is equal to 10% of EN, and DG is equal to 7 lbs. ENGF is the total cylinder volume, and FG is the line of zero pressure.
(3) Lay off the admission, AB equal to 1/5 of AN and DK = 3/5 DO. B is the cut-off point and K is the compression point. Draw vertical lines KM and BL.
(4) From F draw lines intersecting BL and BN. At the intersections with BL draw horizontal lines and at the intersections with BN draw vertical lines. Through these points of intersections draw the expansion curve, a hyperbola.
(5) From F draw lines intersecting KM and KO and repeat (4) to obtain the compression curve, also a hyperbola. (The latter construction is not shown.)

9. Scale 1/2" = 1". Draw the involute cams of Figure 31-IV. Given: Hub circle = 3/4" D. Bore circle = 1/2" D. Key way = 1/16" x 1/8". Distance between hub centers = 4". The involute curves are generated through an angle of 447 1/2$^{\circ}$.

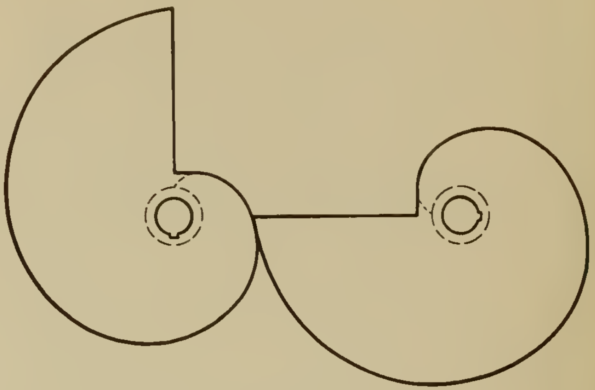


Figure 31-IV. Involute Cams

10. Scale 1" = 1". Draw the involute gear tooth of Figure 32-IV, using the data as shown in the drawing.

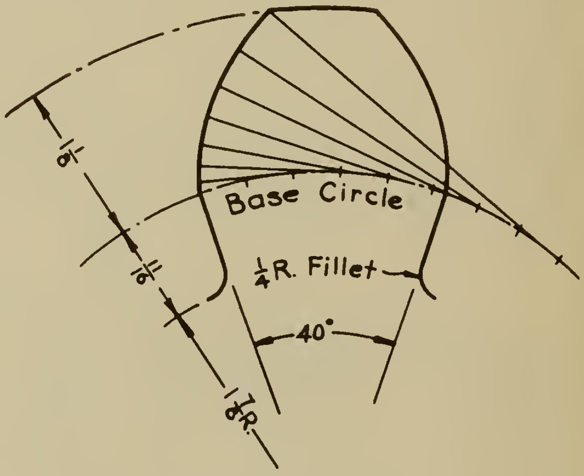


Figure 32-IV. Involute Gear Tooth

11. Scale 2" = 1". Draw the involute toe and wiper cam of Figure 33-IV, using the data as shown in the drawing.

12. Scale 1" = 1". Draw the involute cam of Figure 34-IV, using the following data: Hub circle = 1 1/2" D. Bore circle = 1" D. Key way = 1/8" x 1/4". The involute curves are generated through an angle of 150$^{\circ}$. Line AD is divided as follows: AB = 1/4, and BC = 1/3 of AD.

13. Scale 1" = 1". Draw the torsion spring of Figure 35-IV, using the dimensions and other data shown in the figure. The coiled

spring is shaped to the outline of the spiral of Archimedes. Draw 2 1/4 turns of the spring instead of 2 turns.

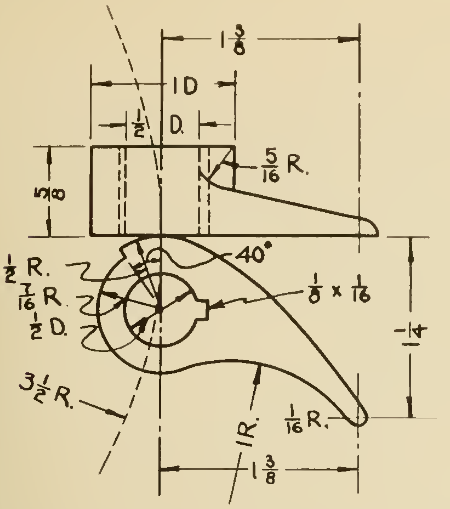


Figure 33-IV. Toe and Wiper Cam

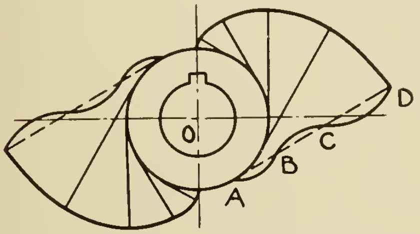


Figure 34-IV. Involute Cam

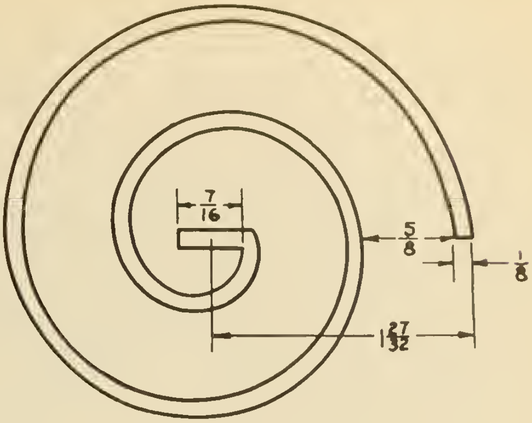


Figure 35-IV. Torsion Spring

14. Scale 3/4" = 1". Pitch = 3/4". Draw the double, V-sharp thread of Figure 36-IV, using the dimensions and other data shown in the drawing. The outline of the thread is a helix, a space curve. Notice the relation between pitch and lead. It is necessary to draw only a half-turn of the crest and root curves, as shown to the left of the thread. These curves can now be transferred to the thread crests and roots (to the right) by transferring points on the curve or by making a templet of hard paper and using this instrument to transfer the curves.

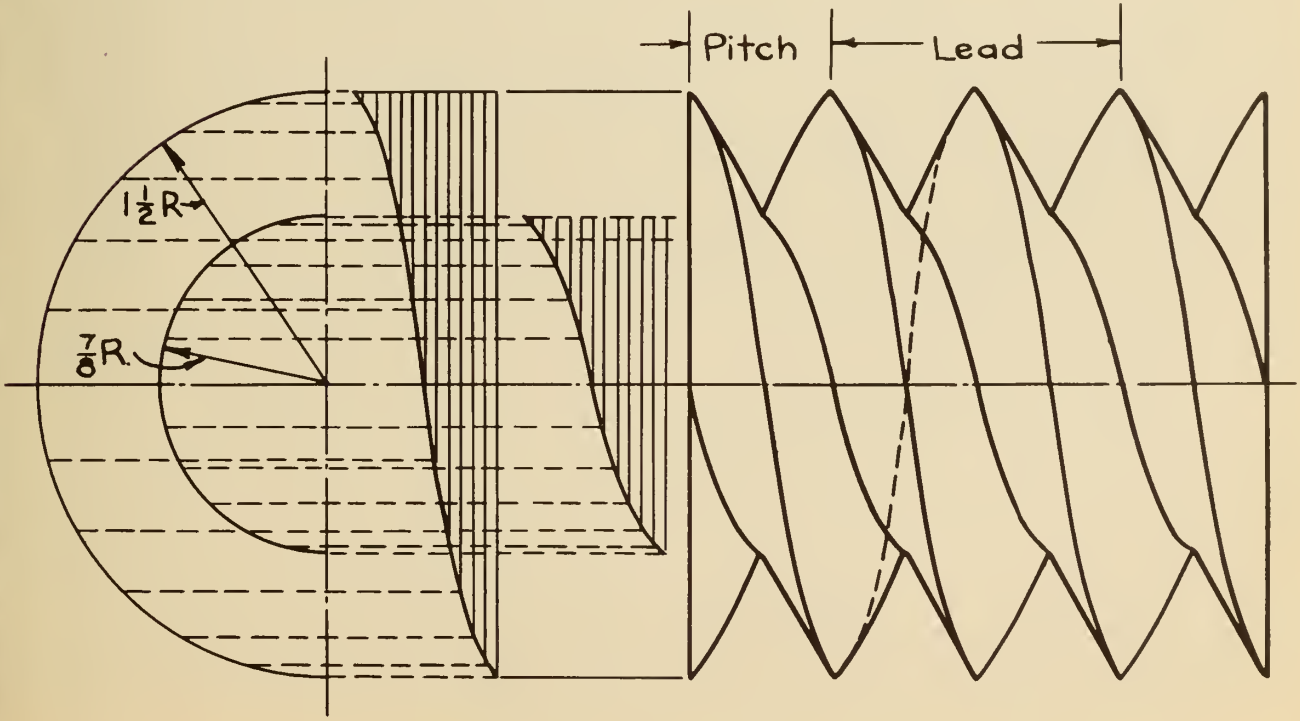


Figure 36-IV. Double, V-sharp Thread

# CHAPTER V

## THEORY OF DRAWING

1-V. The first four chapters of this text were prepared for the purpose of introducing the student to the graphical language, Engineering Drawing. So far, the exercises presented have involved the use of only two dimensions. That is, they were plane geometrical figures. Now it becomes necessary to deal with solid figures which will call for the use of all three dimensions. In order to present full information, a drawing should (1) include the description of the shape of the structure and (2) specify the size of the structure by detailing and dimensioning.

The methods of describing the shape of objects will first be studied. Later on, under dimensions, specifications, and details, the manner of representing the size of objects will be presented.

2-V. Visual Rays. Through the study of geometrical optics, it is known that bodies are seen only by means of light rays coming from the object and striking the observer's eye. These light rays will be defined here as visual rays. The direction of the propagation of the rays and the geometrical shape of the light pencil will depend upon the position of the observer. The visual rays are illustrated by arrows, in Figures 1-V to 4-V. They point out the direction the observer is looking when he sees the object and also indicate the position of the observer. To illustrate, the observer stands in front of the object, Figure 1-V on the following page, to the right of the object, and then above the object and looks in the direction indicated by the arrows. Since the rays are all parallel, his position evidently must be an infinity. In Figure 4-V it can be seen that the visual rays are converging. Therefore, the observer must be standing at a finite distance while viewing the object.

3-V. The Rectangular Coordinate System. Position in space is determined by making definite measurements in specified directions. Usually some point is chosen as the origin from which measurements are made and directions are taken. Such a system, evidently, necessitates the use of all three dimensions, (1) width, (2) height, and (3) depth, Figure 1-V. Measurements are made along lines at right angles to each other that intersect at a point. The point of intersection is the origin, or common point, of the system, and the lines are called the (1) X-axis, (2) Y-axis, and (3) Z-axis, Figures I-V to 4-V. This is called a rectangular coordinate system in which three surfaces are set up at right angles to each other (1) front, (2) top (horizontal), and (3) right side or left side (profile).

From the front of the object there can be seen the X- and Y-axes, Figure 1-V. The Z-axis is seen as a point at the intersection of the other two axes. Distances representing width and height are laid off on lines parallel to the X- and Y-axes, respectively.

The distances representing height and depth are seen from the side of the object and are laid off parallel to the Y- and Z-axes, respectively. The X-axis is a point at the intersection of the other two axes.

When looking at the object from the top, the X- and Z-axes can be seen. Parallel to them are the dimensions marked width and depth. The Y-axis is seen as a point at the intersection of the other two axes.

It can be seen from Figure 2-V that the edges of the prism do not conform to the rectangular dimensions, width, height and depth. These dimensions are always taken parallel to the coordinate axes, X-, Y-, and Z-. However, in Figure 1-V, the edges of the prism are parallel to the coordinate axes and coincide with the rectangular dimensions. The difference in the positions of these two objects is explained in Article 4-V.

4-V. Position of Object and Observer. Usually, engineering structures are rectangular in shape, and in most cases they can be placed in simple position when drawings are made, i.e., placed so the edges of the object are parallel to the coordinate axes as outlined in Article 3-V. It will be recognized that the prism in Figure 1-V is in simple position. The edge AB represents the actual width of the object, AD represents the height, and AC represents the depth. But the prism in Figure 2-V is not in simple position. Therefore, the edges of the object indicated do not represent the three rectangular dimensions. The object is said to be in oblique position. If one face were placed in a coordinate plane, say the horizontal, and the object twisted about a vertical axis so that none of the faces were parallel to the other

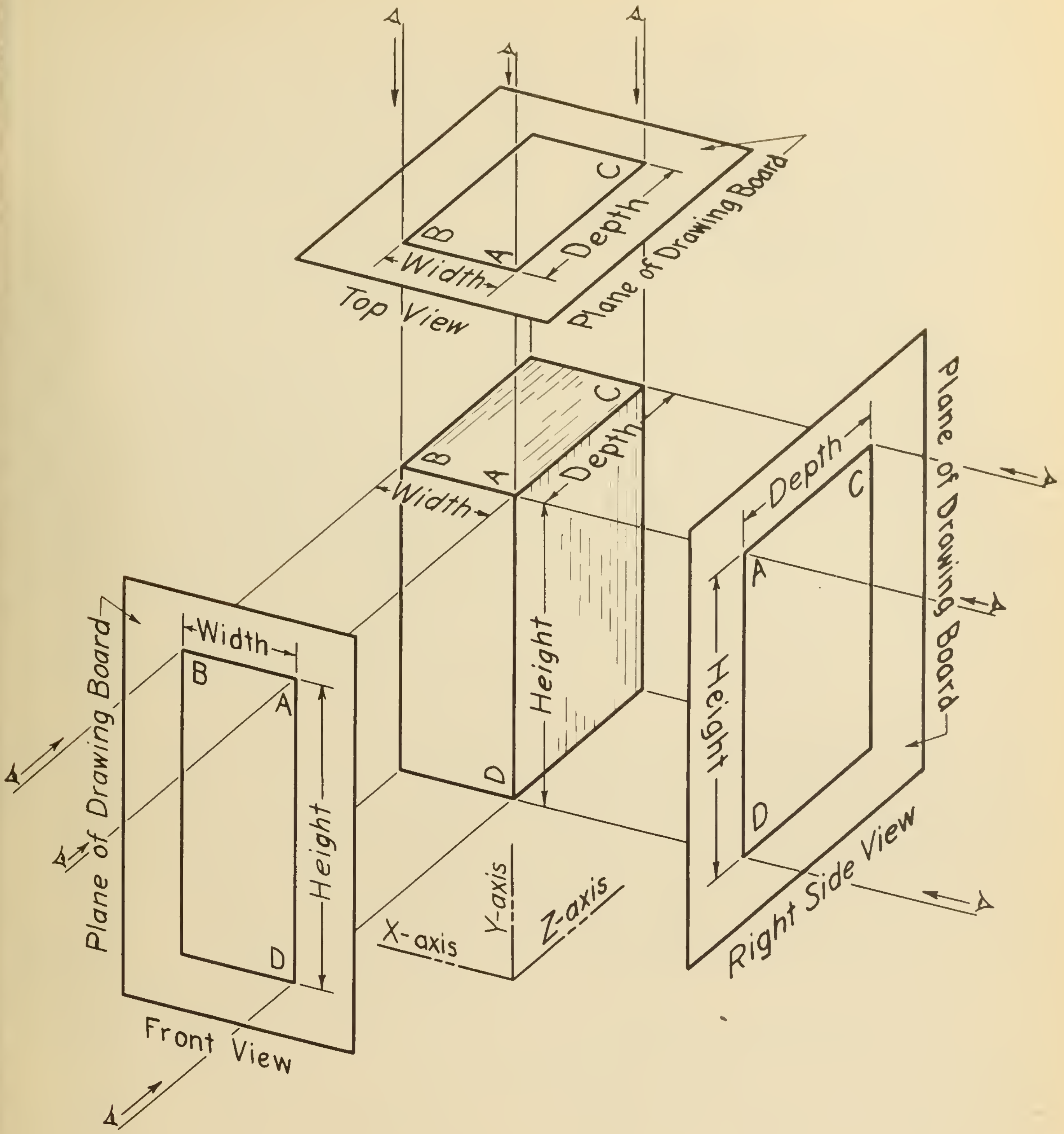


Figure 1-V. Orthographic Representation

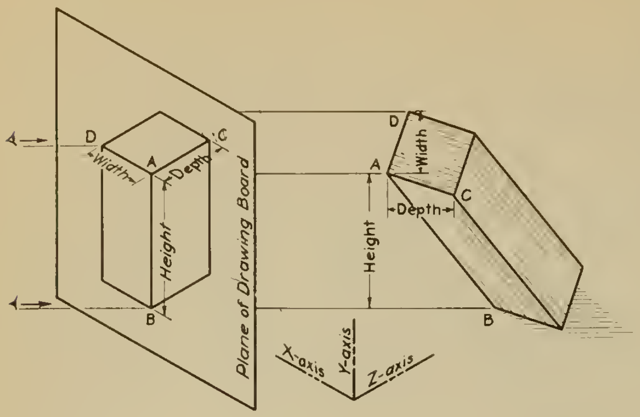


Figure 2-V. Axonometric Representation

two coordinate planes, members BC and AC of the object in Figure 17-VIII (page 81), would then be in auxiliary position. It should be observed that the object is always placed with reference to the coordinate axes.

With the position of the object determined, the optical effect obtained will depend upon the position of the observer, as illustrated in the accompanying drawings. The observer may be at infinity or at a finite distance. Also, he may be looking directly into a face of the object, or at a corner. Figure 6-V is a classification showing the various methods of producing the different types of drawings.

5-V. Engineering Drawings. Drawings intended for use in the design, operation, and maintenance, or construction of engineering works are called engineering drawings or working drawings, Figure 6-V. With the few exceptions noted, they are drawings executed in orthographic. An orthographic drawing is one which represents the observer as being at infinity and which shows the visual rays meeting the plane of the drawing board at right angles. It is sometimes called a "parallel ray, right-angle projection." See Figures 1-V and 2-V.

The problem of the draftsman in producing working drawings is to represent the exact shape of objects, showing three rectangular dimensions. It can be seen from Figure 1-V that all three rectangular dimensions cannot be seen in true length when the object is viewed from any one position. Therefore, it will be necessary to represent the object in at least two views in order to show properly all three dimensions. To illustrate further, when the observer is standing directly in front of the object, the height and width of the prism is seen in true length, but the third dimension, depth, is seen as a point at A. In order to represent the depth of the prism on the drawing, it will be necessary to obtain another view--a side view or the top view. In either side view, height and depth are represented in true length, while the top view will represent the actual width and depth of the prism. It can be seen that engineering drawings are multiview drawings. That is, it takes two or more views fully to represent, detail, and specify an object.

6-V. Axonometric Drawing. It can be seen from Figures 2-V and 6-V and from the definitions given in Article 5-V that an axonometric drawing is an orthographic drawing. It is also a pictorial representation. Since it is a monoview drawing, the rectangular dimensions cannot be represented in actual length. Such distortions will render this type of representation unfit as a working drawing. However, it is used occasionally in representing assembly and special drawings, or to represent in pictorial some unusual detailing. The definition of an orthographic drawing is often written so as to exclude axonometric drawings. It seems more logical to classify the axonometric simply as a pictorial. The term "orthographic" in this work will apply only to multiview drawings.

7-V. Oblique Drawing. An oblique drawing is a pictorial representation, Figure 3-V, in which the observer is represented in an oblique position at infinity. It is a pictorial representation and should not be confused with an auxiliary oblique drawing,

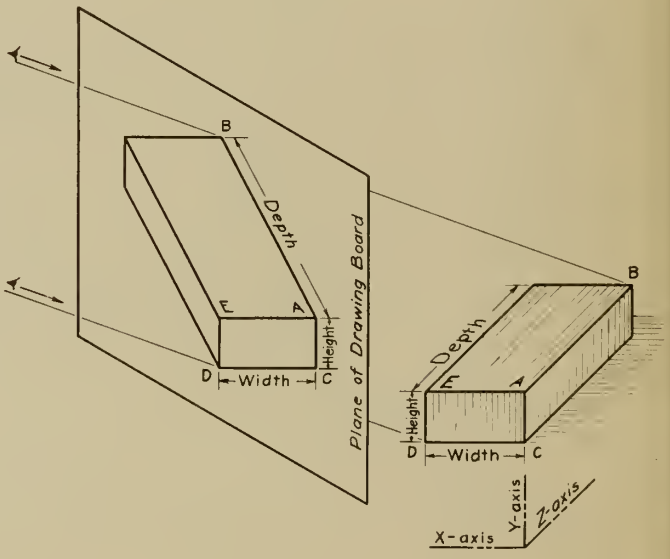


Figure 3-V. Oblique Representation

Figure 7-VIII. Two rectangular dimensions, width, and height, are seen in true length, while the third, depth, might be distorted. Certain kinds of objects are easily drawn in oblique and render pleasing pictorials. For this reason obliques are sometimes used by engineers to make assembly or special drawings, or to represent in pictorial some unusual detailing.

8-V. Perspective Drawing. The perspective is a true scenographic drawing. The object is represented as the camera would photograph it when the photographer is at a finite distance and standing in an oblique position, Figure 4-V. When the observer is so located, all three coordinate axes can be seen, and the visual rays will be converging. This will eliminate certain forms of distortions which naturally appear in other types of pictorial drawings. Lines that are parallel in an object will appear to the eye to converge. The larger the object the more evident is this apparent convergence. Parallel lines are shown as converging lines in perspective, while in axonometric and oblique drawings they are drawn parallel. This discrepancy is usually not displeasing in the representation of small objects but is entirely too noticeable in drawings of large objects. The first two types of pictorials are much quicker and easier to execute than is the perspective.

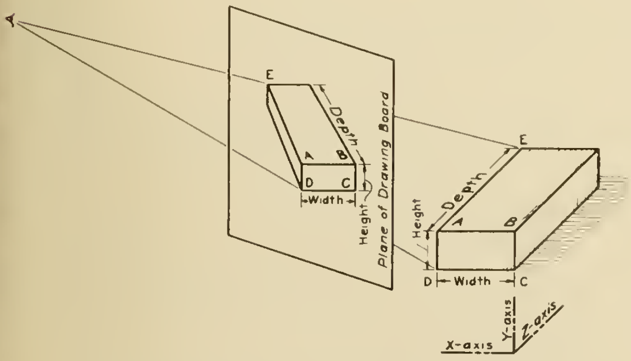


Figure 4-V. Perspective Representation

The architect and artist use the perspective in their scenographic rendering, while the engineer invariably executes his pictorials either in axonometric or oblique, the reason being that the engineer's pictorial drawings are usually of small objects, which will practically eliminate the distortions that would appear in drawings of large objects mentioned above. Then, too, there is effected a saving in time and labor when axonometric or oblique drawings are used. However, a knowledge of perspective will be to the engineer's advantage.

9-V. Principal Views in Orthographic. The upper left-hand drawing of Figure 5-V represents a block in pictorial. The group of drawings in the lower right-hand corner is a system of principal views in orthographic representation. See Article 6-V. The student should observe the method of placing the principal views and the manner of indicating the rectangular dimensions, width, height, and depth. In practice, the various views are not labeled front, left side, top, etc.

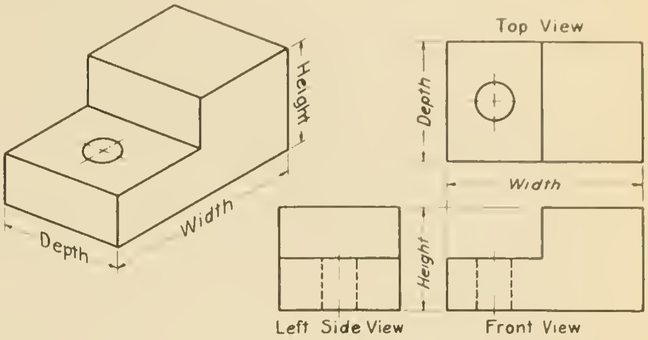


Figure 5-V. Principal Views in Orthographic

EXERCISES

10-V. The following exercises are intended to train the student to visualize an object in pictorial form and then interpret what he sees in terms of orthographic front, top, and side views. It is intended that they shall be drawn with instruments, but it will furnish valuable training for the student if they are done free hand on either plain or coordinate paper.

The exercises of this set should occupy a space 8" x 8".

### Group 1-V. Pictorial Drawing in Isometric

1. Reproduce Figure 1-V, substituting for the rectangular prism a right, regular, square prism. Sides of prism 3/4". Axis 1 1/4". Mount the prism on a square plinth. Sides 1 1/2". Altitude 1/2". The axes of both solids are vertical and coincide. Place one side of each base parallel to the X-axis.

   The pictorial in Figure 1-V is an axonometric drawing. The student should

Drawings Classified

- Orthographic Drawings (Observer at infinity)
  - Working Drawings (Multiview. Usually two or more views) See Figure 1-V
    - I. Detail Drawings
      - (1) Principal Views
        - (a) Front
        - (b) Top
        - (c) Side
      - (2) Auxiliary Views
        - (a) Elevation
        - (b) Front or Rear
        - (c) Right or Left
        - (d) Oblique
      - (3) Sectional Views (usually combined with other views)
        - (a) Half-section
        - (b) Full-section
        - (c) Revolved-section
        - (d) Phantom-section
    - II. Assembly Drawings
      - (1) Sectional
      - (2) Outline
      - (3) Pictorial (see pictorial drawings)
    - III. Special
      - (1) Diagram
      - (2) Erection
      - (3) Display (often in pictorial)
      - (4) Charts and Graphs
  - Axonometric Drawings (Monoview) See Figure 2-V
    - I. Isometric
      - Visual rays make equal angles with three faces of object. Therefore, equal measurements are made on all three isometric axes or lines parallel to them. (One scale)
    - II. Dimetric
      - Visual rays make equal angles with two faces of object; unequal angle with third face. Equal measurements on two axes; unequal on third. (Two scales)
    - III. Trimetric
      - Visual rays make different angles with all three faces of object. Unequal measurements along all three axes of object. (Three scales)
- Oblique Drawings (Observer at infinity)
  - Monoview Drawings (A single view) See Figure 3-V
    - I. Cavalier
      - Angle of obliquity of visual rays equal 45 degrees.
    - II. Cabinet
      - A Cavalier drawing with dimensions parallel to receding axis reduced one-half.
    - III. Special
      - Special angle of obliquity of visual rays.
    - IV. Pseudo-perspective
      - Visual rays slightly converging so as to reduce distortion along receding axis. Converging angle of rays arbitrarily chosen to give pleasing effect.
- Perspective Drawings (Observer at a finite distance)
  - Monoview Drawings (A single view) See Figure 4-V
    - Scenographic
      - (1) Object in simple position. Lines parallel to one pictorial axis converge. One point perspective.
      - (2) Object in auxiliary position. Base of object horizontal. Lines parallel to two pictorial axes converging. Two-point perspective.
      - (3) Object in oblique position. Lines parallel to all three pictorial axes converge. Rarely used. Three-point perspective.

Orthographic Drawings

Pictorial Drawings

Figure 6-V. A Classification Showing the Various Methods of Producing the Different Types of Drawings

first visualize the objects and then draw the two as directed in axonometric representation. Next draw the three orthographic views as indicated. The descriptive matter given in the illustration should be reproduced.

2. For the prism of Problem 1, substitute a right-angle triangular prism. The two legs of the right angle are 3/4". Axis 1 1/4". Place one leg parallel to the Z-axis.
3. For the prism of Problem 1, substitute a hexagonal prism. Distance across corners is 1". Axis 1 1/4". Place one edge of the hexagon parallel to the Y-axis.
4. For the prism of Problem 1, substitute a right pyramid. Base square. Sides 1". Axis 1 1/2". Place one side of base parallel to the Y-axis.
5. For the prism of Problem 1, substitute a right cone. Diameter of base 1". Axis 1 1/2".
6. For the prism of Problem 1, substitute a right cylinder. Diameter 1". Axis 1 1/4".

### Group 2-V. Pictorial Drawing in Oblique

1. Make an oblique drawing of the object listed below. Both drawings in Figure 3-V are oblique representations. The right-hand drawing of Figure 4-V is an oblique. Visualize the object and draw in oblique what you see. Next, draw the orthographic front, top, and right side views as indicated in Figure 1-V. Reproduce the descriptive matter as illustrated.

   Draw a right cylinder. Base 1", and parallel to the X-Y surface. Axis 2".
2. For the cylinder in Problem 1, substitute a right cone.
3. For the cylinder in Problem 1, substitute a right pyramid. Base square with 1" sides and one side parallel to the Y-axis. Axis 1 1/4". Base parallel to the X-Y surface.
4. For the cylinder in Problem 1, substitute a solid symmetrical cross. One member is vertical, the other is horizontal. Their axes are the perpendicular bisectors of each other, therefore their faces coincide. A right section of each member is 3/4" square and each member is 2" long. Place the face of the cross parallel to the X-Y surface. The cross is made of one solid piece.
5. For the cylinder in Problem 1, substitute a solid cylindrical wheel. Diameter 1 3/4". Thickness 3/4". An axle 1/4" in diameter is flush with the back side and extends 7/8" in front of the wheel. The face of the wheel is parallel to the X-Y surface.

### Group 3-V. Change of Pictorial Form

1-3. Scale 3/4" = 1". Figures 7-V, 8-V, and 9-V. These objects are drawn in isometric as indicated. Redraw, using oblique representation instead of isometric. Then draw the front, top, and right side views as indicated in Figure 1-V. Indicate the position of observer and direction observer is looking when all three views are seen. Draw the X-, Y-, and Z-axis. Show the three rectangular dimensions. In Exercise 3, Figure 9-V, the student can draw directly on the pictorial the involutes (and circular arc) shown to the left. This

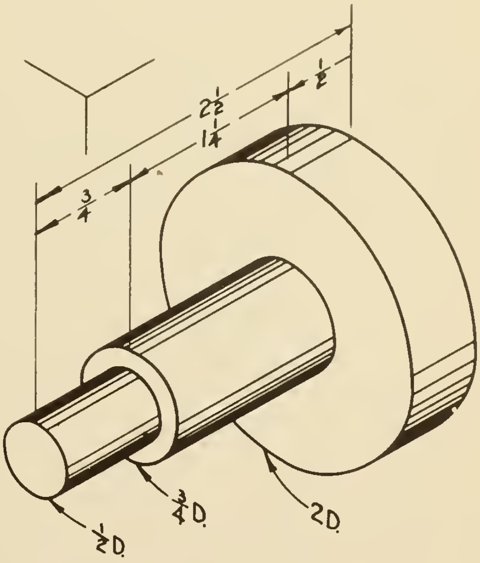


Figure 7-V. Core

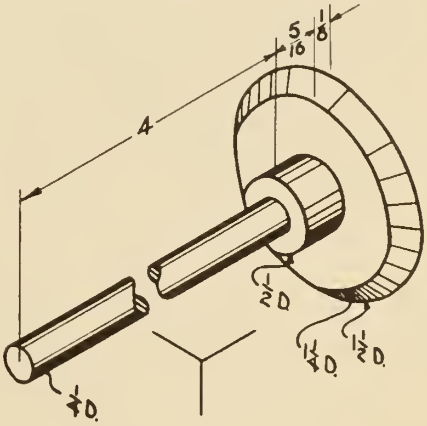


Figure 8-V. Valve and Stem

diagram is shown with rectangular coordinates and is a true representation of the outline of the cam.

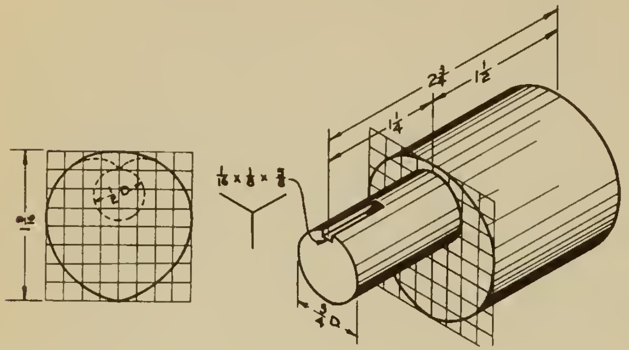


Figure 9-V. Involute Cam

4-6. Scale 3/4" = 1". Figures 10-V, 11-V, and 12-V. These objects are drawn in oblique as indicated. Redraw, using isometric representation instead of oblique.

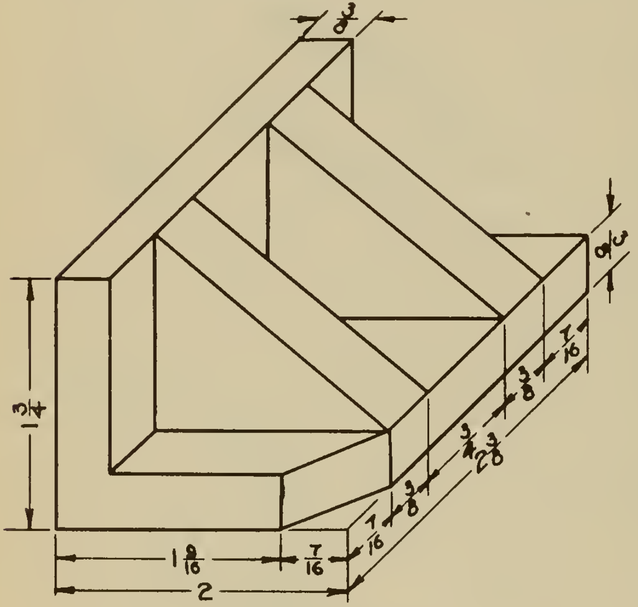


Figure 10-V. Bracket

Then draw the front, top, and right side views as indicated in Figure 1-V. Indicate the position of observer and direction observer is looking when all three views are seen. Draw the X-, Y-, and Z-axis. Show the three rectangular dimensions.

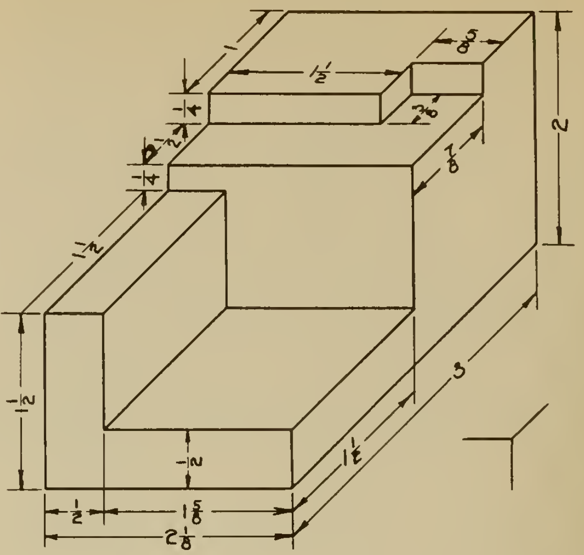


Figure 11-V. Block

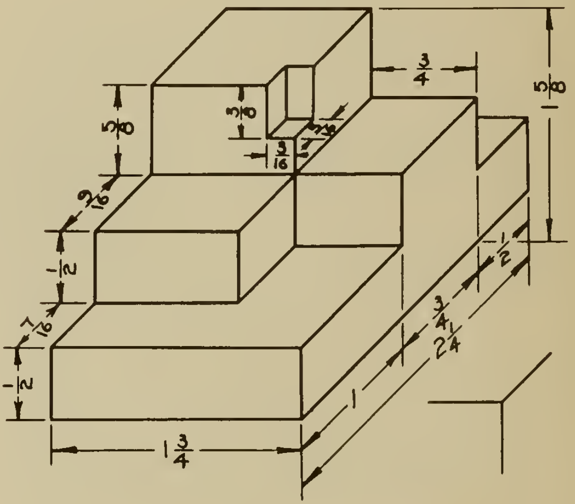


Figure 12-V. Block

## Group 4-V. Principal Views in Orthographic

1-6. Scale 3/4" = 1". Draw three principal views (in orthographic) of Figures 7-V, 8-V, 9-V, 10-V, 11-V, and 12-V. See Figure 5-V. Do not label the views "Front", "Top", etc.

# CHAPTER VI

## PRINCIPAL VIEWS

1-VI. Man-built structures are essentially rectangular in shape and constructed in such a position that the edges and faces are vertical and horizontal. The more complicated structures are composed of combinations of the simpler geometrical solids, such as the right prism, pyramid, cylinder, cone, and the like. When possible, the structure is placed in simple position. No doubt this custom has grown up around the natural laws of economy and the desire for simplicity and ease in designing and building structures. Special attention is always attracted to objects that are not rectangular or are oblique in position.

The rectangular dimensions, width, height, and depth, are fully described in the previous chapter. It should be pointed out here that these dimensions do not necessarily represent the over-all dimensions of the structure. They are dimensions taken in specified directions and at right angles to each other.

2-VI. Description of Structures. The function of principal views is to represent the exact shape of a structure. To do this the three rectangular dimensions must be represented in true lengths. A drawing so executed must include at least two of the principal views, Figures 6-V, 1-VI, and 2-VI. The entire group of principal views will include the front, top, and side views, together with the less frequently used bottom and rear views. Each one of the above views can show but two of the three rectangular dimensions. It is often necessary to draw auxiliary (additional) views in order completely to describe a structure or to solve some problem pertaining thereto, Chapter VIII.

3-VI. Relative Position of Observer. Figure 1-VI represents a block in pictorial, showing all three dimensions but not in true length. Figure 2-VI is a drawing of the same block in principal views showing the front, top, and right side drawings of the object. The front view is the one about which the other principal views radiate. It is drawn first. The observer is thought to be directly in front of the block (at infinity) when this view is drawn. The width and height of the block are seen in true lengths, but the dimension depth is a point and cannot be

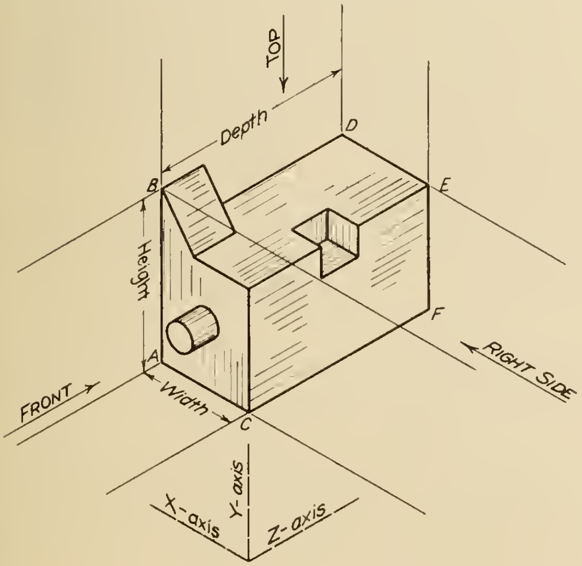


Figure 1-VI. Block. A Three-Dimension Representation

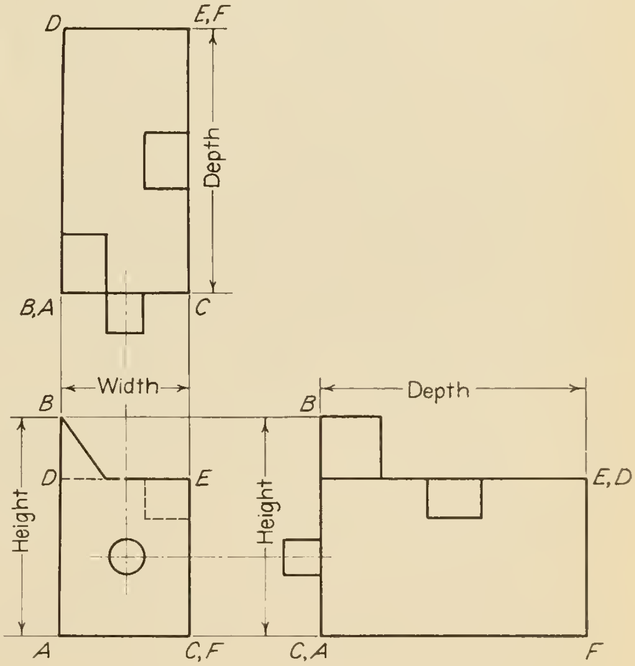


Figure 2-VI. Principal Views of Block, Figure 1-VI

seen. Edges that cannot be seen (hidden outlines) are represented by dotted lines. It can be seen that points A, B, and C are on the front of the block, while D, E, and F are on the rear face. The relative position of these points, i.e., whether or not F is in front or behind C, cannot be shown until another view is drawn. From the top or side view it can be seen that F is behind C. The point nearest the observer should be written first, i.e., C should be to the left of F in the front view.

The top view is always drawn directly above the front view with the visual rays coming from B and E connecting the two views but not quite touching the drawings. In this view the observer is thought to be standing directly above the object (at infinity) and looking straight down. His position is such that the back of the object is shown farthest from him, i.e., the rear of the structure is at the top of the drawing. In making a drawing of the bottom, however, the rear of the structure will be seen at the bottom of the drawing. In the top view, B is nearest the observer, D and E are next in position, and A, C, and F are farthest away. Therefore, the lower left-hand corner should be lettered BA and the upper right-hand corner designated as EF. There are no hidden outlines in this view. The dimension width is common to the front and top views.

The right side view is always drawn directly to the right of the front view, while the left side view would be drawn directly to the left, with the visual rays connecting points B and C but not quite touching the drawing, Figure 2-VI. The observer is thought to be standing directly to the right of the block (at infinity) in this view, looking straight into the right side. His position is such that the side C, F, E is nearest to him while surface A, B, D is farthest away. Also, D, E, F will be to his right while A, B, C will lie to the left, i.e., the rear of the structure will always be to the right, while in the left side view, the rear will lie to the observer's left. The lower left-hand corner is designated as CA and the upper right as ED. There are no hidden outlines in this view. The dimension height is in common with the side and front views, while depth is in common with the side and top views.

The block of Figure 1-VI contains three unusual details. It has a cylindrical boss protruding from the center of the front face (a positive cylinder), a triangular prism rising above the top surface at the front left-hand corner (a positive prism), and a rectangular prism cut into the right and top surfaces of the block (a negative prism). From the front view the geometrical shape of the cylindrical object can be determined, but it is not known whether or not the cylinder is positive or negative. It can be seen, however, that the prism at B is positive while the other one is negative, but the shapes cannot be determined from this view. In the top view the geometrical shape of the cylinder is not shown, but it can be seen that it is a positive object. The reverse is true of the two prisms, i.e., their shapes are shown, but it cannot here be determined whether or not they are positive or negative. In the side view the triangular and cylindrical bosses are shown as positive structures, but their geometrical shapes cannot here be seen. The rectangular prism is shown in true outline in the side view, but it cannot be determined whether or not the prism is a boss or a hole until another view is consulted.

It can be seen that two views will be sufficient properly to describe this particular block, the front and either the side or top view. In this particular case the side view is probably of more value than the top.

4-VI. Rules for Grouping Views. From the foregoing discussion, the following rules are formulated for the proper placing of principal views:

1. Draw the front view first. All other principal views must radiate from the front view. Select for the front that view which will tell an observer the most about the object, i.e., that face which best shows the configuration of the structure.
2. The top view should always be placed directly above the front with the rear of the structure at the top of the drawing.
3. The right side view should always be placed directly to the right of the front with the rear of the object at the right of the drawing.
4. The left side view should be placed directly to the left of the front view with the rear of the structure at the left of the drawing.
5. The bottom view should always be placed directly below the front view with the rear of the object at the bottom of the drawing.
6. The front and top views or the front and bottom views should be connected with vertical visual rays, not quite touching the drawings, as indicated in Figures 2-VI, 4-VI, and 6-VI.

The front and right side views or the front and left side views should be connected with horizontal visual rays, not quite touching the drawings, as indicated in Figures 2-VI, 4-VI, and 6-VI.

5-VI. Exercises in Reading Principal View Drawings. Figure 3-VI is a pictorial representation of a dovetail block. Three principal views of the same block are shown in Figure 4-VI. The student should study carefully the pictorial drawing and then, without the aid of Figure 4-VI, sketch at least five of the principal views representing the block. He can then compare his sketches with Figure 4-VI as a check. A similar procedure is recommended for Figure 6-VI. Both drawings contain some interesting details that will be incorporated in plate work later on.

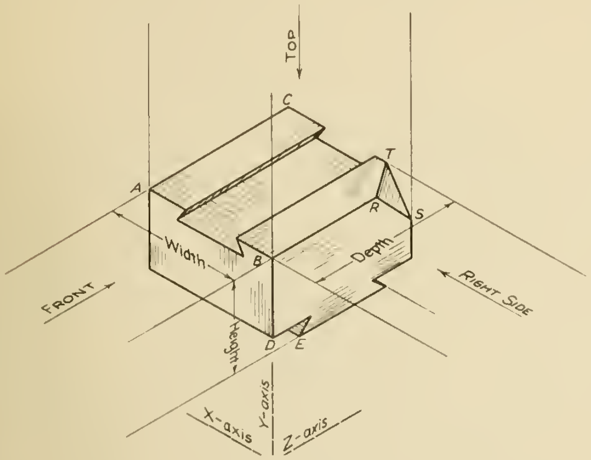


**Figure 3-VI. Dovetail Block. A Three Dimension Representation**

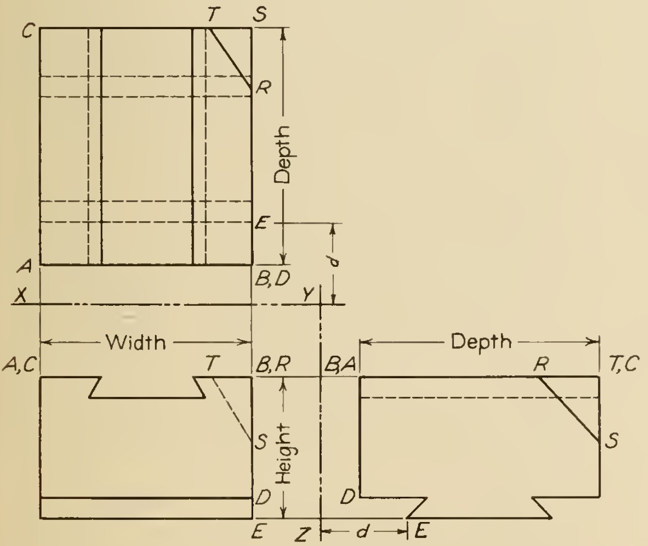


**Figure 4-VI. Principal Views of Dovetail Block, Figure 3-VI**

It should be noticed that lines AC and BR are points in the front view, Figure 4-VI, and the lines BA and TC are points in the side view, etc. Also, lines AB and BD are in true length in the front views, lines BD and BR are in true length in the side view, etc. But lines RS and RT are foreshortened (not in true length) in the front view, although line ST is seen in true length in this view. Similarly, in the side view, lines TS and TR are foreshortened, but line RS is seen in true length. The same is true of surfaces, i.e., ABD and BES are lines in the front view, but ABD and CTS are seen in their exact shapes and sizes. In the side view, ABD and CTS are seen as lines, while BES is seen in true area and shape. Surface RST is not seen in true size or shape in any of the principal views.

In Figure 4-VI, the front and top views are given and it is required to draw the right side view of the block. The reference planes X-Y and Y-Z are drawn at a convenient distance from the front view. Horizontal visual rays are drawn from the front to the right, and on these rays distances are laid off which were taken from the top view. Point E, for example, is located in the side view by taking the distance d which E in the top view is from X-Y and laying this distance off on ray E, measuring from plane Y-Z.

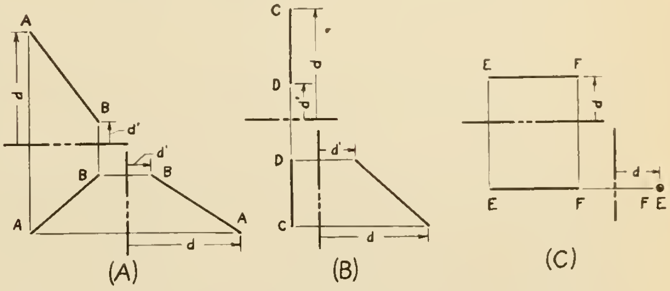


**Figure 5-VI. Principal Views of a Line**

Figure 5-VI (A), (B), and (C) illustrates the manner of drawing the right side views of lines AB, CD, and EF respectively, when the front and top views are given. The procedure is as described above. Line AB is in oblique position; CD is a profile line, i.e., parallel to a side plane (plane Y-Z); and line EF is parallel to a frontal and a level plane (planes X-Y and X-Z, respectively). Line EF is therefore perpendicular to a side plane and is seen as a point in the side view.

Attention is called to the cylindrical surface forming the trough of the bracket in Figure 6-VI, an anchor block. The cylindrical surface comes tangent to the right side surface along a horizontal line through point T and parallel to the Z-axis. It can be seen that the line just described is not shown in the pictorial drawing or in the orthographic side view. If it were represented in the side view it would be a dotted line through point T in place of the center line so drawn.

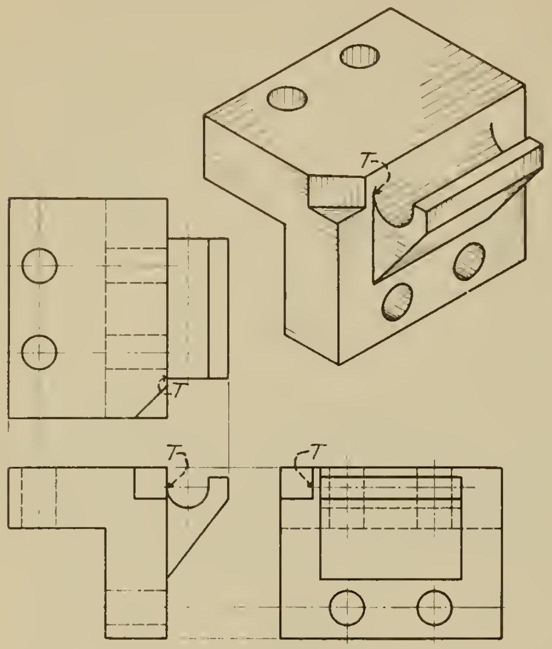


Figure 6-VI. Anchor Block With Principal Views

It should be noticed that the front corner of the anchor block is notched by a vertical and a horizontal plane. Also a rear corner of the dovetail block is cut away by an oblique plane, RST. The student should compare the manner of representing these two details in the corresponding principal views. He should also be able to interpret the meaning of each dotted line in all the drawings of this chapter.

6-VI. Orthographic Representation. From the reading exercises of Article 5-VI, the following principles of orthographic representation are formulated:

1. A line parallel to the visual rays is seen as a point.

2. A line perpendicular to the visual rays is seen in true length.

3. A line making an oblique angle with the visual rays is foreshortened and is not seen in true length.

4. A surface parallel to the visual rays is seen as a line.

5. A surface perpendicular to the visual rays is seen in true area and shape.

6. A surface making an oblique angle with the visual rays is foreshortened and is not seen in true area and shape.

## EXERCISES

7-VI. The exercises of this chapter are intended primarily as practice in representing the true shape of objects. They might be used, however, as introductory problems to working drawings, Chapter XIV, by having the student include the size of the structures by giving the proper dimensions and specifications. If this should be done, the chapter on dimensioning, Chapter X, should first be assigned. The dimensions should be placed according to the rules prescribed, then carefully checked.

If drawn to full scale, or the scale indicated, the exercises of this group will occupy a space 5 1/2" x 6 1/2". A greater reduced scale than the one given can still be used.

### Group 1-VI. Principal View Representation

1. Draw the front, top, and left side views of the block of Figure 2-VI. Scale the dimensions from the figure, take dimensions to the nearest 1/32". Take the right side view of Figure 2-VI as the front view. Scale 1 1/2" = 1".
2. Draw the front, top, and right side views of Figure 4-VI. Scale the dimensions from the figure. Take dimensions to the nearest 1/32". Take the right side view of Figure 4-VI as the front view. Scale 1 1/2" = 1".
3. Draw the front, bottom, and left side views of Figure 6-VI. Scale the dimensions from the drawings in the text. Take dimensions to the nearest 1/32". Scale 1 1/2" = 1".
4. Figure 7-VI, on the following page. Scale 1/2" = 1". Draw the front, top, and right side views.
5. Figure 8-VI, on the following page. Scale 1/2" = 1". Draw the front, top, and right side views.
6. Figure 9-VI, on the following page. Scale 1/2" = 1". Draw the front, top, and left side views.
7. Figure 10-VI, on the following page. Scale 1/2" = 1". Draw the front, top, and left side views.

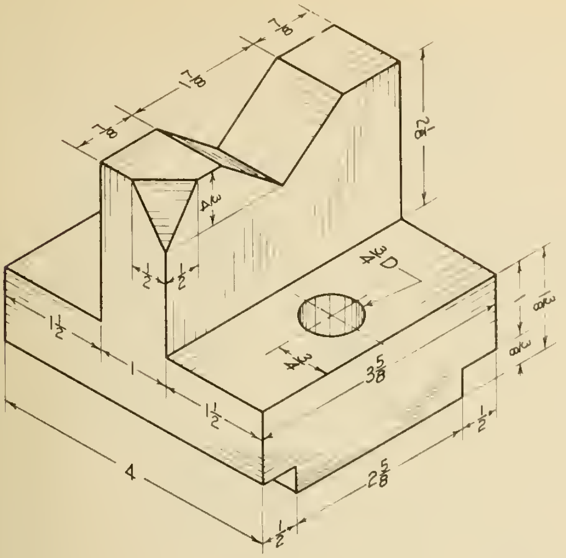


Figure 7-VI. Special Drill Jig

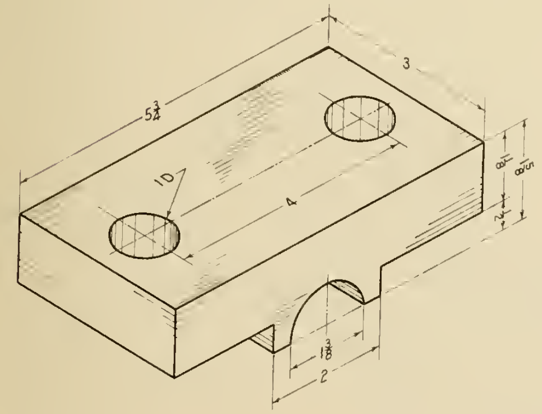


Figure 8-VI. Bearing Cap

8. Figure 11-VI, on the following page. Scale 1/2" = 1". Draw the front, top, and right side views.
9. Figure 12-VI, on the following page. Scale 1/2" = 1". Draw the front, top, and right side views.
10. Figure 13-VI, on the following page. Scale 1/2" = 1". Draw the front, top, and left side views.

Group 2-VI. Missing View to be Supplied

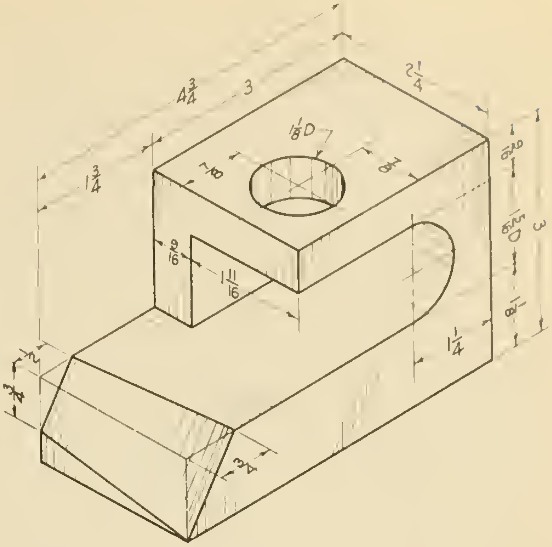


Figure 9-VI. Special Drill Jig

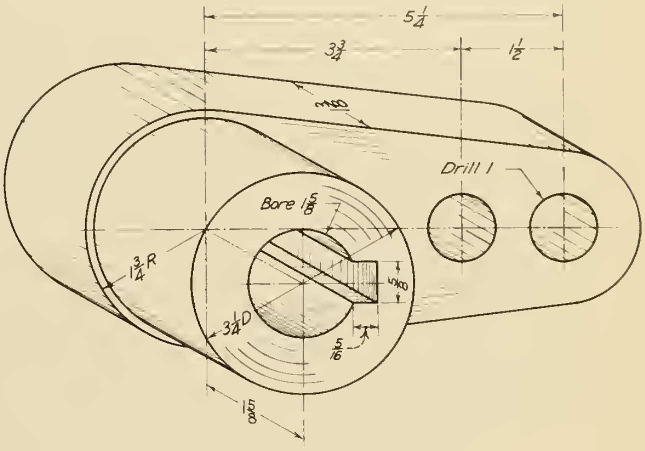


Figure 10-VI. Dash Pot Arm

1-4. Scale 1" = 1". Figures 25-III, 26-III, 27-III, and 28-III. Any one of these drawings represents one view of an object. Each drawing is one view taken from a set of principal view drawings. Only two rectangular (over-all) dimensions can here be shown. Draw the missing view or views which will complete the set of principal view drawings. Supply missing dimensions or details, using dimensions you think would be reasonable.

5. Scale 1/2" = 1". Figure 31-IV. See exercise 9, Group 2, Ch. IV, for complete data for the exercise. Follow instructions given in exercise 1 above.

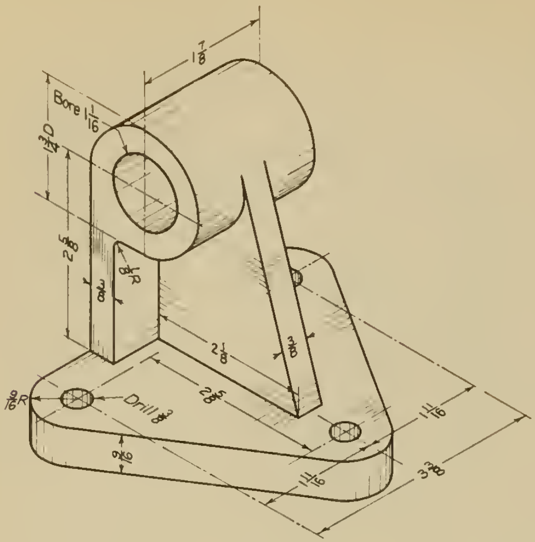


Figure 11-VI. Bracket

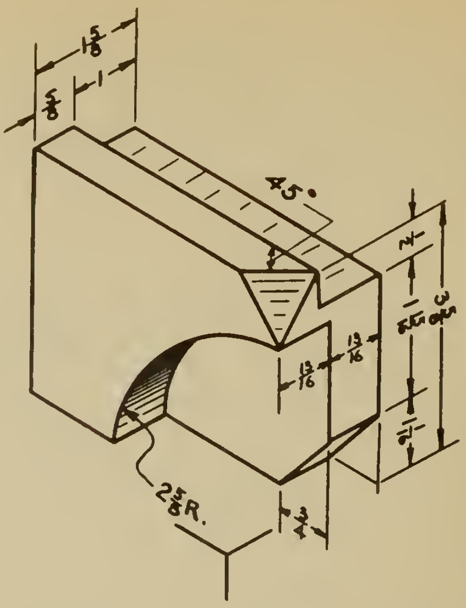


Figure 12-VI. Back Rest for Lathe

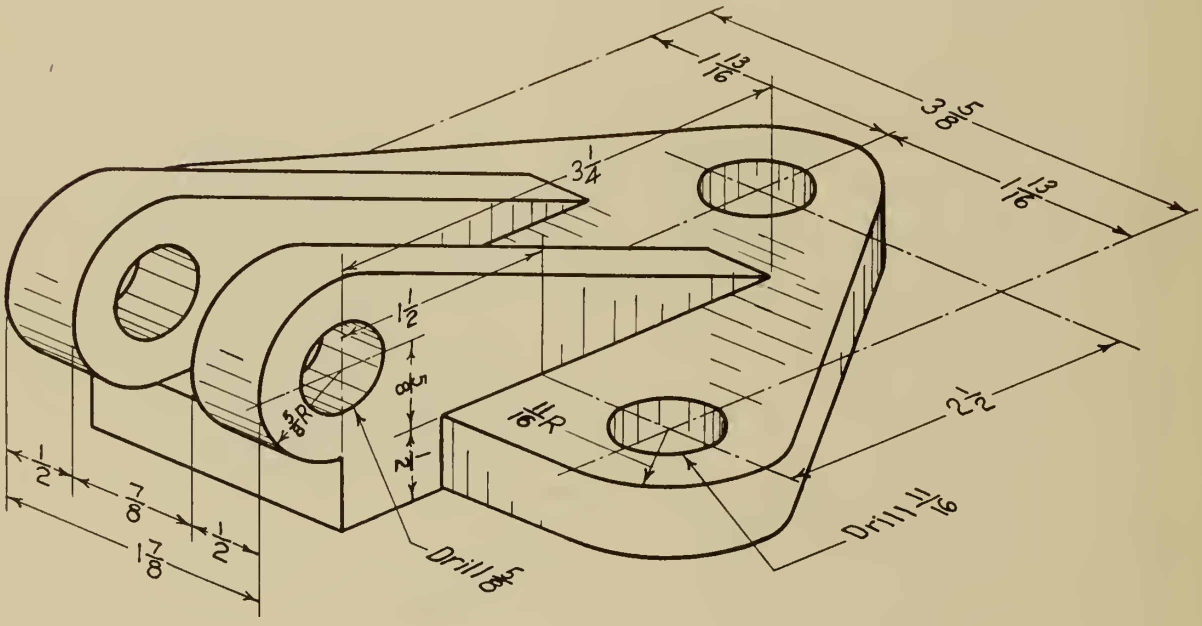


Figure 13-VI. Hinge Bracket

6. Scale 1" = 1". Figure 33-IV. See EXERCISE 11, Group 2, Ch. IV, for complete data for the exercise. Follow instructions given in exercise 1 on the preceding page.
7. Scale 1/2" = 1". Figure 34-IV. See EXERCISE 12, Group 2, Ch. IV, for complete data for the exercise. Follow instructions given in exercise 1 on the preceding page.
8. Scale 1" = 1". Figure 35-IV. See EXERCISE 13, Group 2, Ch. IV, for complete data for the exercise. Follow instructions given in exercise 1 on the preceding page.

### Group 3-VI. Principal Views of a Line

1-3. Scale 1" = 1". Figure 14-VI (A), (B), and (C). The rectangular divisions of the graph, Figure 14-VI, are equal to half-inch. Given the front and left side views of a line, draw the top view.

### Group 4-VI. Principal Views of a Triangle

1-4. Scale 1" = 1". Figure 14-VI (D), (E), (F), and (G). The rectangular divisions of the graph, Figure 14-VI, are equal to half-inch. Given the front and top views of a triangle, draw the left side view.

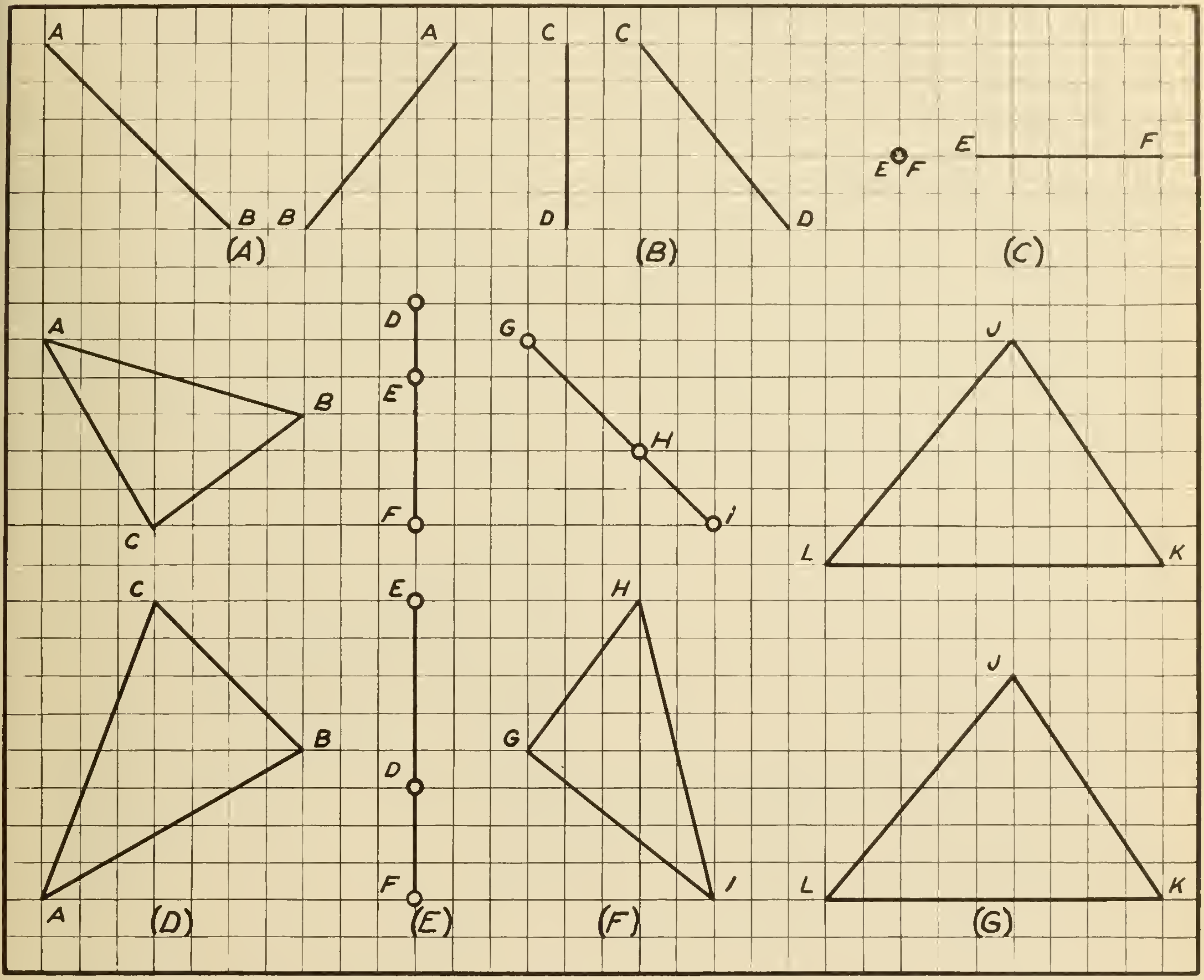


Figure 14-VI. Principal Views of Line and Triangle

# CHAPTER VII

## SECTION DRAWING

1-VII. It is often difficult, if not impossible, to show clearly the interior details of the more complicated structures by the use of dotted lines (hidden outlines). Too many hidden outlines cause flatness, that is, not enough contrast. In order to obtain a clearer description, the object is theoretically cut, and the portion of the structure between the observer and the cutting plane is removed in the sectional view only, Figures 1-VII and 2-VII. The observer is then able to see the interior details beyond the cutting plane, and dotted lines become full lines or are removed entirely, and the object is more readily visualized. The cut material which is exposed to the observer's view is represented in the sectional view by means of crosshatching or section lining.

2-VII. Sectional Views. It should be clearly understood that the process of cutting an object in order to obtain a section is strictly theoretical, although in the sectional view, front views, Figures 1-VII and 2-VII, that part of the object between the observer and the cutting plane is actually removed in the front view but in the front view only.

When the cutting plane removes the entire front portion of the object, the front view is said to be in full section, as section A-A Figure 1-VII, meaning a full section on plane A-A. When a front quarter of the object is removed, the front view is then said to be a half-section, section M-N Figure 2-VII, on the following page, and not a quarter-section. A quarter-section is a certain division of land. The entire front view

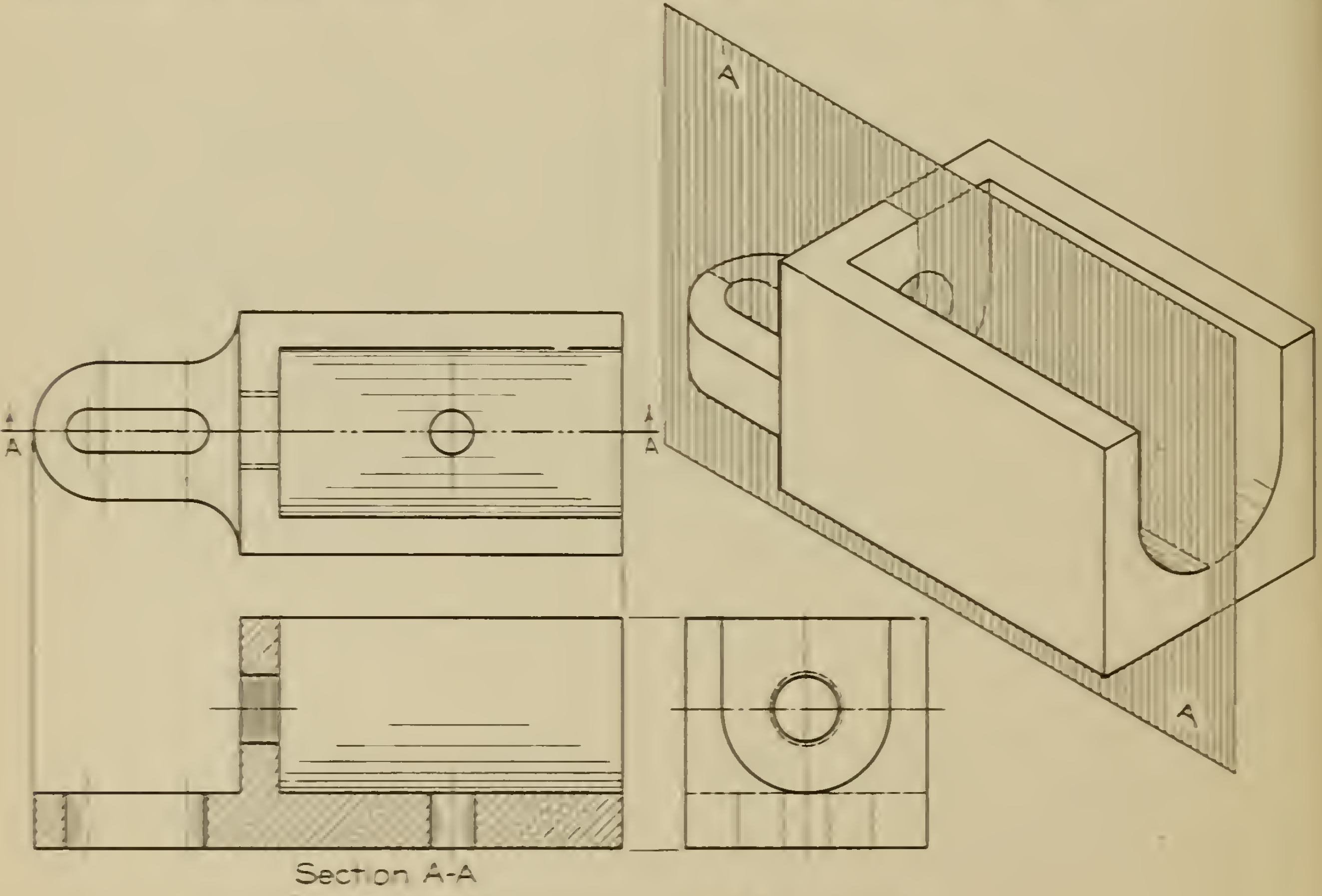


Figure 1-VII. Full Section on Cutting Plane A-A

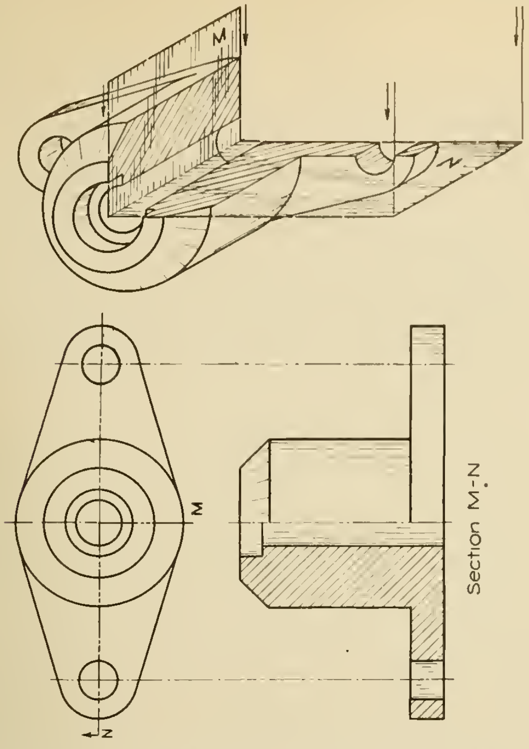


Figure 2-VII. Half-Section on Cutting Plane M-N

of Figure 2-VII is a sectional view and not just the right half.

The left half of the front view, Figure 2-VII, shows only lines of the exterior of the object, while the right half of the drawing shows the interior detailing of the object. All hidden outlines are omitted. A center line is shown in section M-N in place of the visible outline made by cutting the object. It also replaces the cutting plane line. Cutting plane lines are shown only once. They are shown in the top view in this case.

Cutting planes may be broken or offset, as illustrated in Figures 2-VII and 3-VII. In the latter drawing the plane is offset in order to show the more difficult detailing. The position of the cutting plane is shown in the top view, the plane is labeled, arrows are drawn to indicate the direction the observer is looking, and the sectional view is marked. In drawings of the simpler objects it is not always necessary to locate the cutting plane or label the section. The more detailed procedure listed above, however, is recommended for the beginner, even though he be making one of the simpler drawings.

Principal views are sometimes given special treatment in representing sections, as in Figure 6-VII. The left-hand object, front view, is represented in phantom section. Cutting planes are omitted, but certain detailing which the draftsman wishes to emphasize is crosshatched with broken lines. When a massive object is cut and sectioned, as the right-hand object in Figure 6-VII, the crosshatch lines are not run through but are drawn only around the outline, leaving the center of the mass blank. This is termed outline sectioning.

3-VII. Idioms. It should be noticed in Figure 3-VII that the

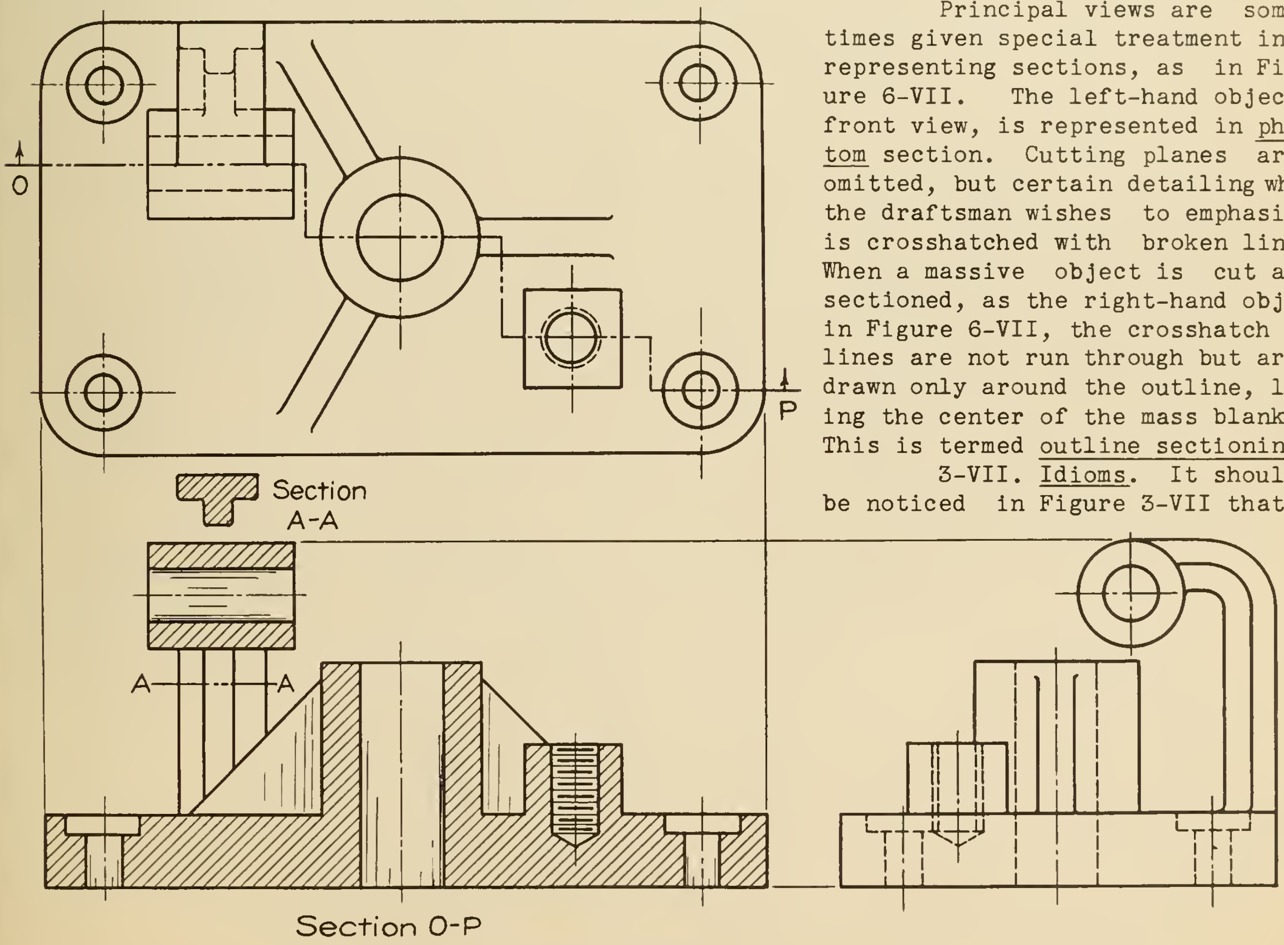


Figure 3-VII. Offset Section Cutting Plane O-P

strict principles of drafting have been violated, i.e., the countersunk hole to the left in section O-P is shown in the plane of the section, though actually it is not in the plane. One of the two flanges, or supports to the left of the vertical cylinder in the center of the object is shown revolved into the plane O-P but is not sectioned. Also the support to the right is cut but is not sectioned. Symmetrical parts should appear to be symmetrical in all views. These violations are known as idioms of drafting. Similar violations are seen in Figures 4-VII, 5-VII, 6-VII and 7-VII. When it is found possible to violate the strict rules of drafting and thereby improve a drawing in appearance and clearness, making it easier and quicker to read, the draftsman should violate those theories. Figure 5-VII illustrates some common conventional intersections and idioms of drawings.

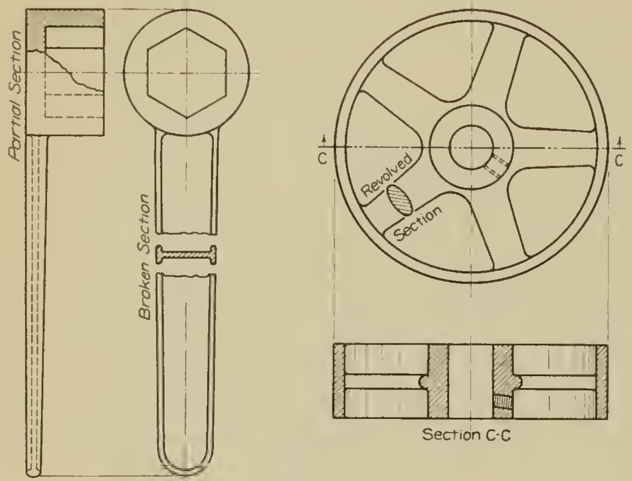
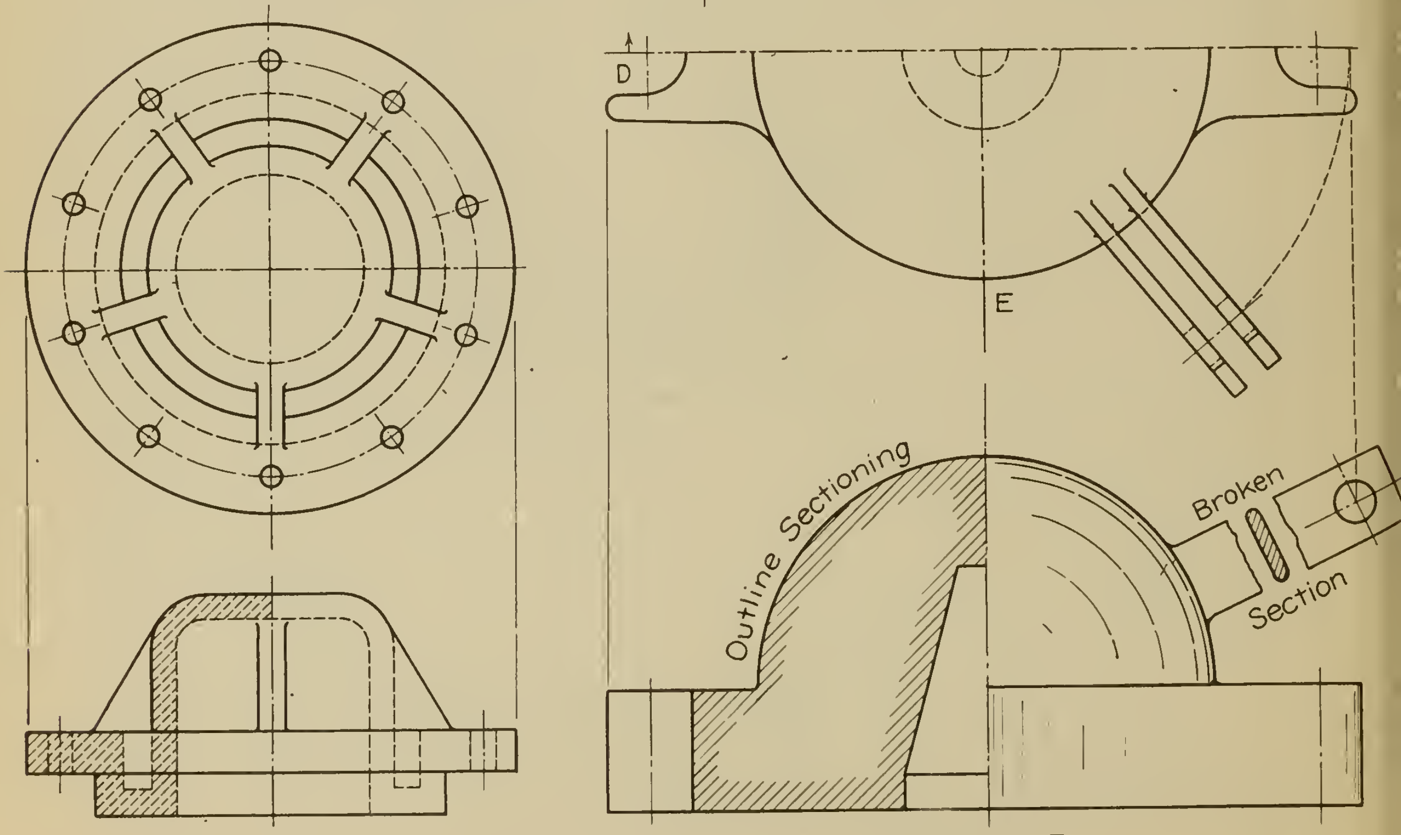


Figure 4-VII. Study in Sectioning

4-VII. Special Sections. Heretofore the section on a cutting plane has been combined with a principal view in what was termed a sectional view. It is often possible to show a neat section on the cutting plane only, generally omitting a view of the remainder of the piece, which will represent the structural or geometrical shape of the object where it is cut. These sections are not separate views. With the exception of the removed section, the cutting plane is not shown. Since it is a neat section, arrows representing the direction of vision are not drawn. The more common special sections are:

1. Removed section. Figure 3-VII, Sec. A-A.



Phantom Section

Section D-E

Figure 6-VII. Study in Sectioning

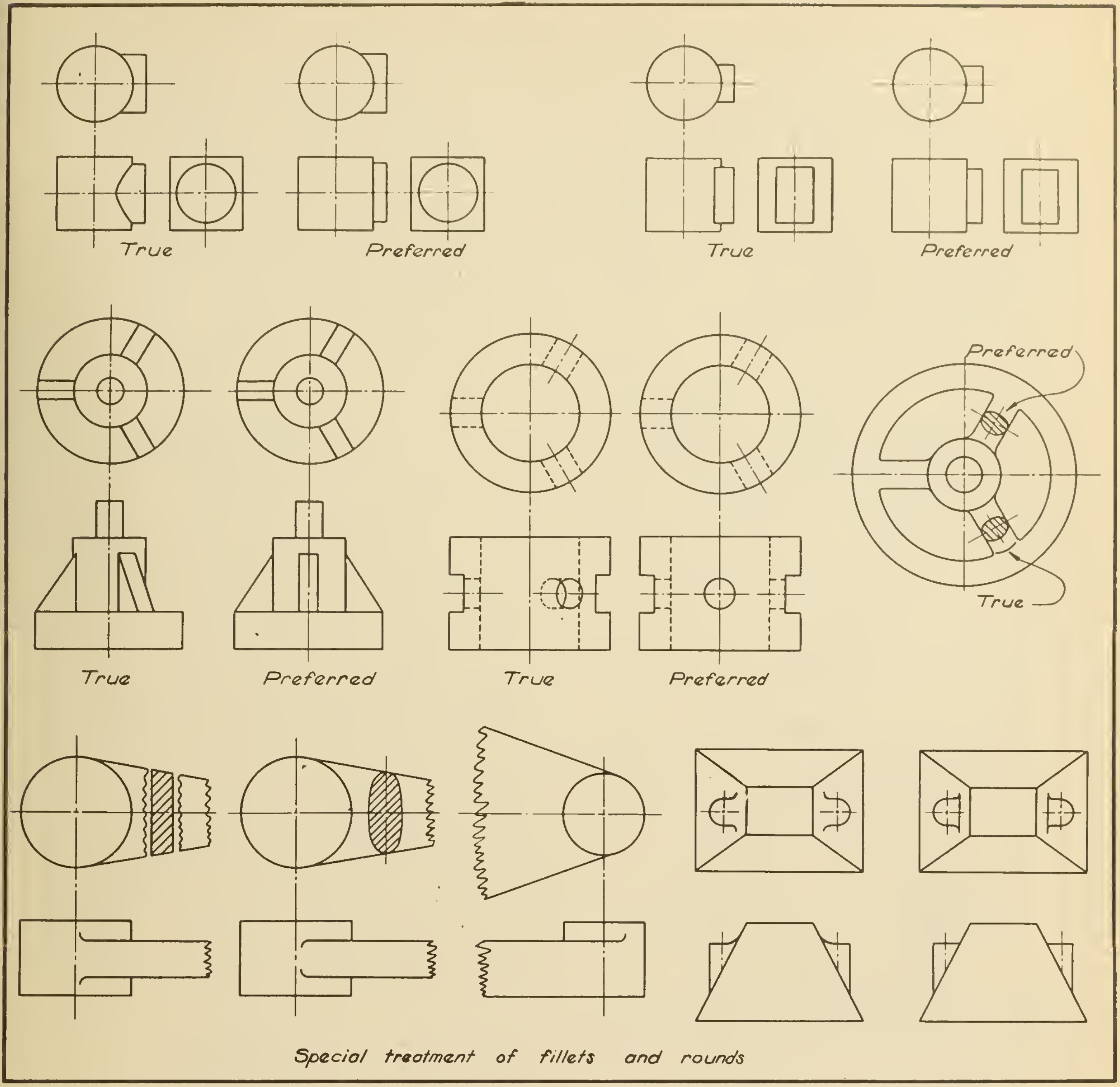


Figure 5-VII. Conventional Intersections and Idioms of Drawing

2. Partial section, Figure 4-VII.
3. Broken section, Figures 4-VII and 6-VII.
4. Revolved section, Figure 4-VII.
5. Conventional break, at the upper end of the vertical shaft, Figure 7-VII.

When materials are shown in section they are represented with crosshatch lines which are spaced, sloped, or broken, according to the conventions listed in the Appendix. For cast iron, the lines are sloped at an angle of 45 degrees and spaced approximately 1/16 inch apart, the distance being judged by the eye; adjacent pieces are crosshatched in opposite directions, Figure 7-VII.

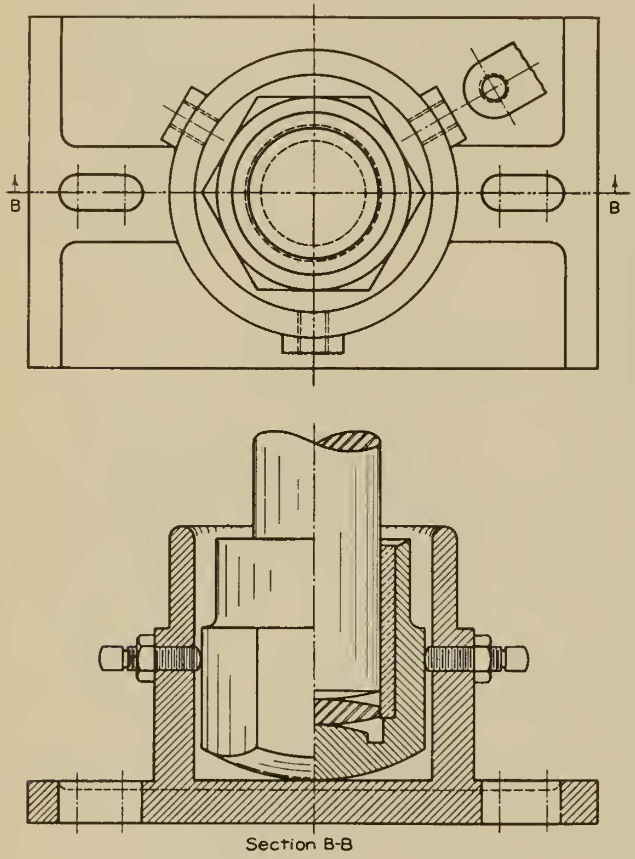


Figure 7-VII. Study in Sectioning

A thrust bearing is shown in Figure 7-VII with idioms as indicated. The pedestal and bowl are cast iron. A vertical steel shaft is resting on a steel thrust bearing and is supported by a bronze bushing. The bowl is adjusted by three set screws with square heads, cinched with lock nuts. The screws are represented in one view only. The shaft is broken and sectioned in accordance with the convention. The bowl is cut in full but shown in half-section. The screws are revolved into the plane of the section but are not shown sectioned. It was necessary to show a dotted line in order completely to describe the object without drawing a separate view.

5-VII. Summation of Principles. 1. The cutting plane may be offset in order to show the details to better advantage.

2. Invisible lines should be omitted in a sectional view unless they are necessary for the description of the piece.

3. Crosshatch lines in adjacent pieces are sloped in opposite directions.

4. The parts of an object which have no interior detailing to be shown, such as shafts, rods, rivets, bolts, nuts, keys, pins, and the like, whose axes occur in the plane of the section, are left in full and are not sectioned.

5. The same piece occurring in different views or in different parts of the same view should be crosshatched identically in direction and spacing of lines.

6. The division line in a half-section, i.e., the line separating the details of the exterior from those of the interior of a sectional view, should be a center line rather than a visible outline or a cutting plane line.

6-VII. To Cut a Section. The five steps for making a section drawing and the order in which they should be made are:

1. Locate the cutting plane by drawing a dash-double-dot line.

2. Point arrows to indicate the direction in which the observer is looking when the cut material is seen.

3. Label the cutting plane (M-M, etc.).

4. Mark the section view (Section M-M, etc.).

5. Draw the crosshatch lines to represent the cut material.

## EXERCISES

7-VII. The exercises of this chapter might be used as introductory problems to working drawings, Chapter XIV, by having the student include the size of the structure by giving the proper dimensions and specifications. If this were done, the chapter on dimensioning, Chapter X, should first be assigned. The dimensions should be placed according to the rules prescribed, then carefully checked.

If drawn to full scale, or in the scale indicated, the exercises of this group will occupy a space 5 1/2" x 8 1/2", except as indicated. A greater reduced scale than the one given may still be used.

In order to obtain a wider choice of problems, the instructor may assign objects from the exercises of Chapter VI, Principal Views, to be sectioned as directed.

### Group 1-VII. Specified Sections

1 and 2. Figures 8-VII and 9-VII. Make a two-view drawing of the object. Show the right half of the front view in section. Scale 3/4" = 1".

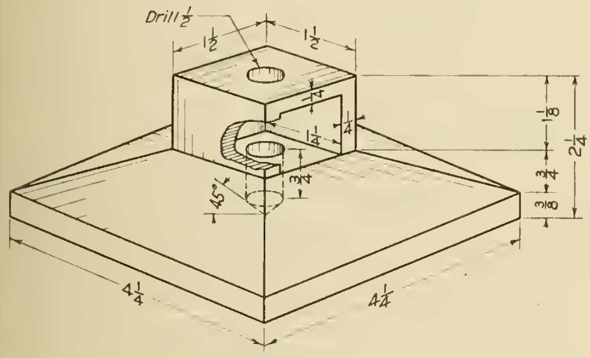


Figure 8-VII. Foundation Washer

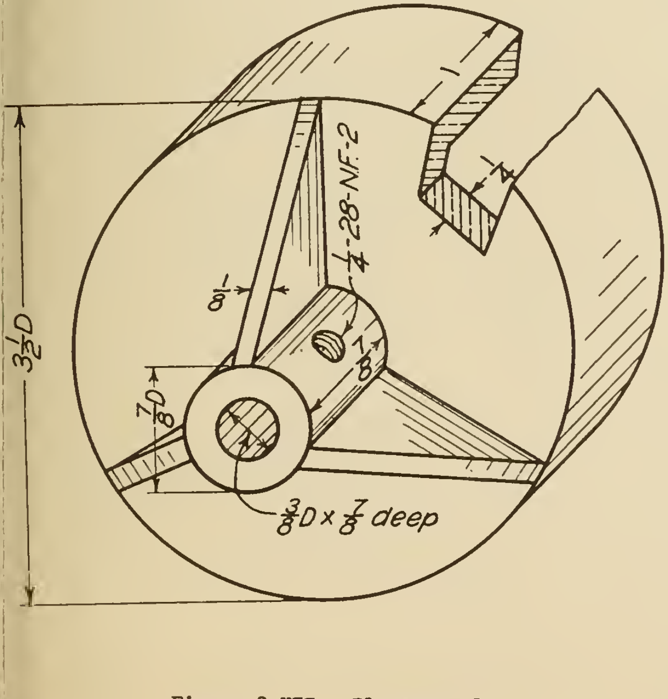


Figure 9-VII. Plunger Valve

3. Figure 10-VII. Make a two-view drawing of the object. Show the front view in half-section. Scale 1/2" = 1".

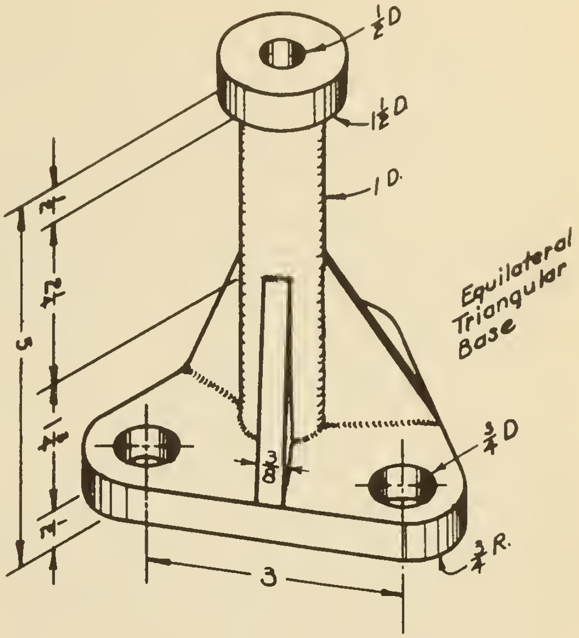


Figure 10-VII. Stem Support

### Group 2-VII. Sections to be Chosen

1. Figure 11-VII. Problem, space 8 1/2" x 11". Make a three-view drawing of the object. Cut the necessary section in order properly to describe the structure. Scale 1/2" = 1".

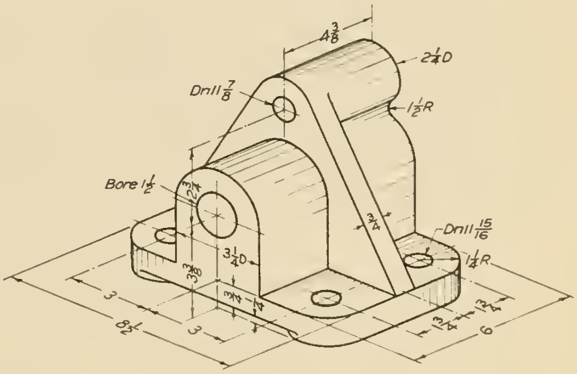


Figure 11-VII. Brake Lever Bracket

2 and 3. Figures 12-VII and 13-VII on the following page. Make a two-view drawing of the object. Cut the necessary sections

in order properly to describe the structure. Scale 3/4" = 1". Problem space 8 1/2" x 11".

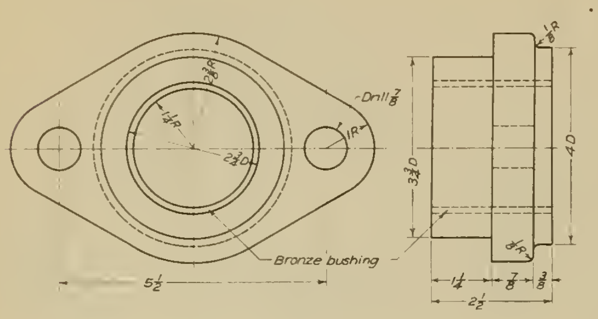


Figure 12-VII. Bearing

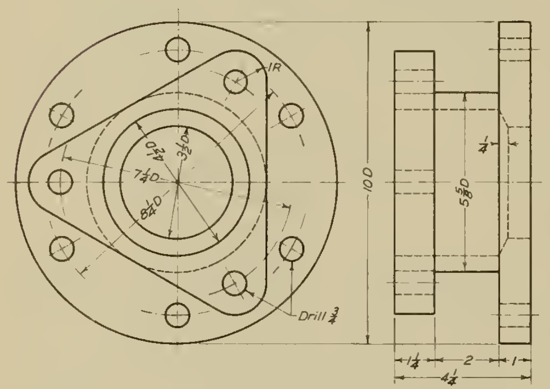


Figure 13-VII. Gate Valve Stuffing Box

4. Scale 1" = 1". Figure 5-X. Cut the necessary section in order properly to detail the object. Draw a babbit bearing in place, 1/4 inch thick. Show fiber shims in place (one on each side).
5. Scale 3/4" = 1". Figure 6-X. Show the necessary views and sections properly to describe the piece.

### Group 3-VII. View to be Completed and Sectioned

1. Scale 1" = 1". Figure 14-VII. Reproduce the drawings as given with the necessary changes which will properly show the upper half of the left view in section.
2. Scale 1" = 1". Figure 15-VII. Reproduce the drawing as given with the necessary changes which will properly show the left half of the front view in section.

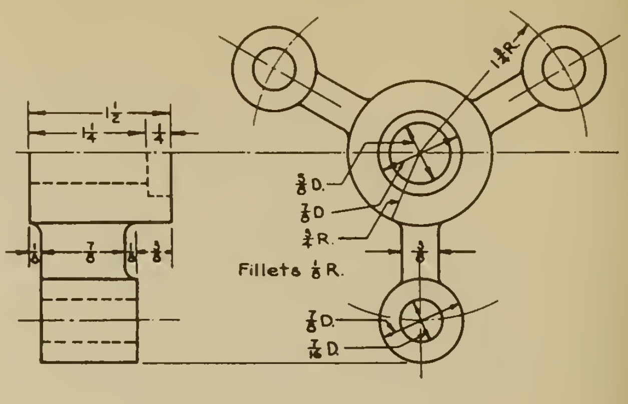


Figure 14-VII. Spider

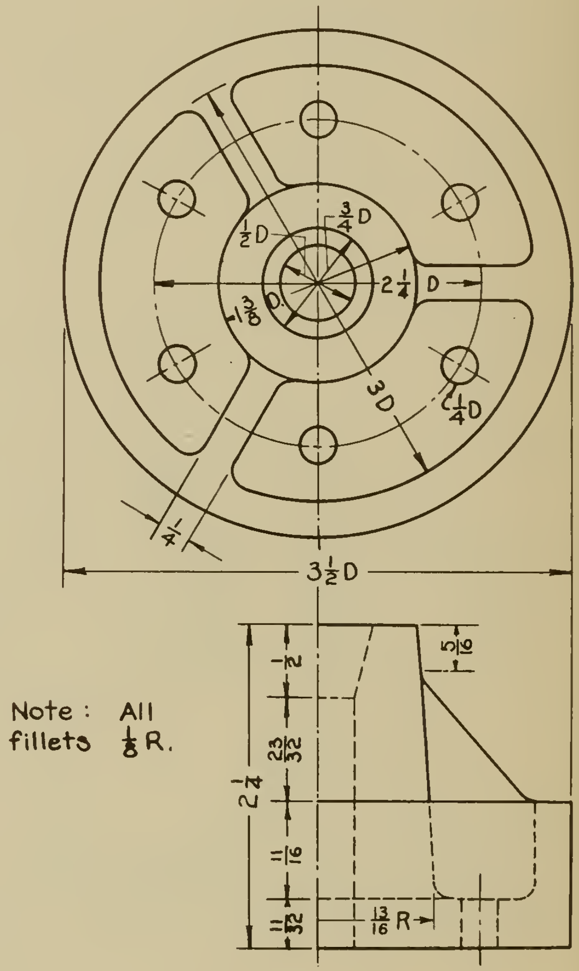


Figure 15-VII. End Plate

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# CHAPTER VIII

## AUXILIARY VIEWS

1-VIII. As outlined in Chapter VI, it is often necessary to make drawings of structures or parts of a structure that are not in simple position. They are inclined to the visual rays of the principal views and are therefore not in true representation in the principal view drawings. In order to show the true area and shape of a surface, the visual rays must strike that surface at right angles. That is, the direction of the observer's sight must be perpendicular to the surface. In order to represent the true area and shape of a surface not in simple position, an additional or auxiliary view must be drawn along with the principal views.

Any principal view will show two of the three rectangular dimensions, which has already been pointed out, but it will be shown later that an auxiliary view will contain not more than one rectangular dimension. In the case of the auxiliary oblique, no rectangular dimension is shown. There are two types of auxiliaries: (1) primary and (2) secondary. The primary auxiliaries consist of (a) auxiliary elevation, (b) auxiliary right or left, (c) auxiliary front or rear. The secondary auxiliary is an auxiliary oblique and is taken from a primary auxiliary. It is an auxiliary of an auxiliary.

2-VIII. Auxiliaries Defined. In Figure 1-VIII, the entire system of auxiliary views is illustrated. At the center left of the drawing, a pictorial illustrates the direction an observer is looking when the various views are seen. The following definitions will illustrate:

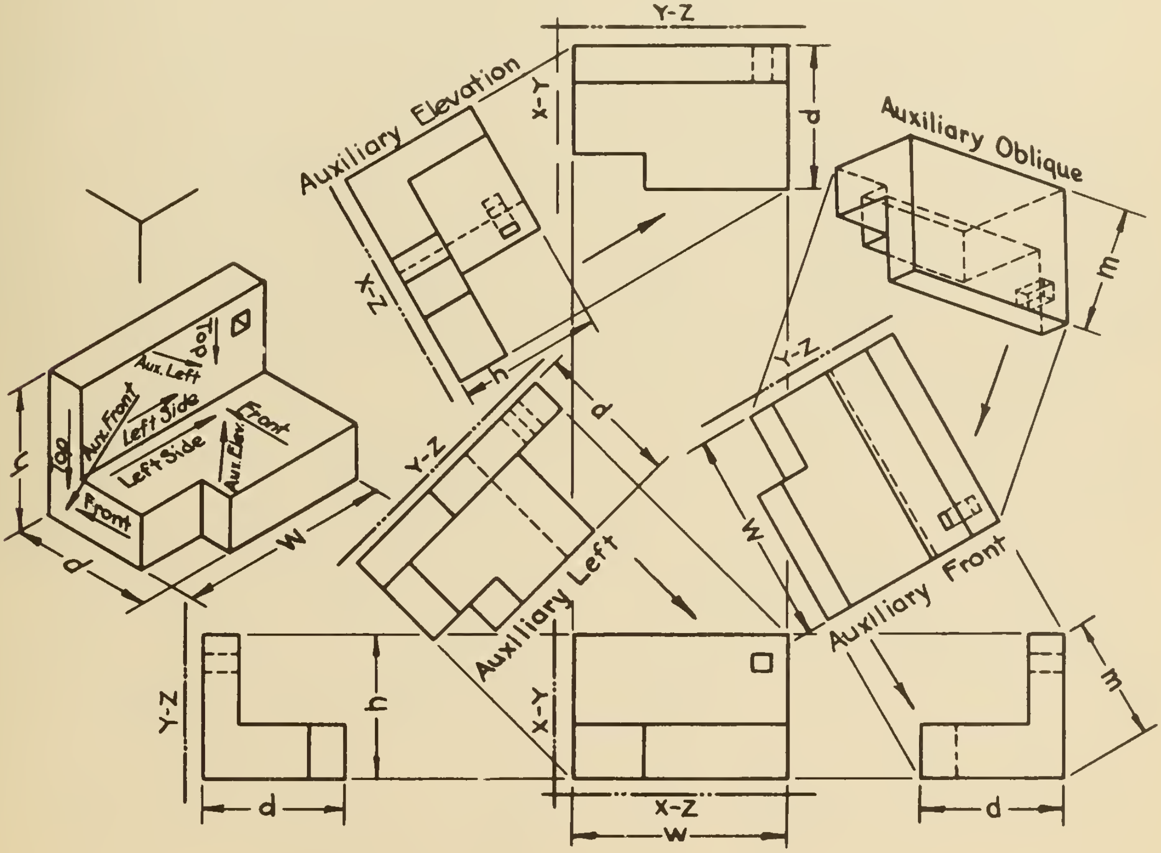

Figure 1-VIII. Auxiliary Views Illustrated

1. An auxiliary elevation of an object is any view--other than a principal view --taken in a horizontal direction, Figures 1-VIII and 2-VIII.

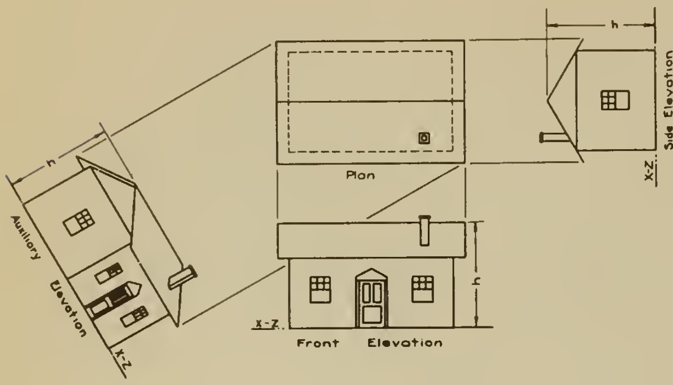

Figure 2-VIII. Auxiliary Elevation of a House

2. An auxiliary right or left of an object is any view--other than a principal view--taken in a frontal direction, Figure 1-VIII.

3. An auxiliary front or rear of an object is any view other than a principal view--taken in a profile direction, Figure 1-VIII.

4. An auxiliary oblique is any view taken in a direction which is inclined to the horizontal, frontal, and profile directions, i.e., the direction of sight of the observer is an oblique line.

Figure 3-VIII illustrates a system of auxiliary views in which a truncated prism is used and rotated into different positions in order that the inclined face 1-2-3-4 could be used in each case to illustrate a certain kind of auxiliary view. In position (A),

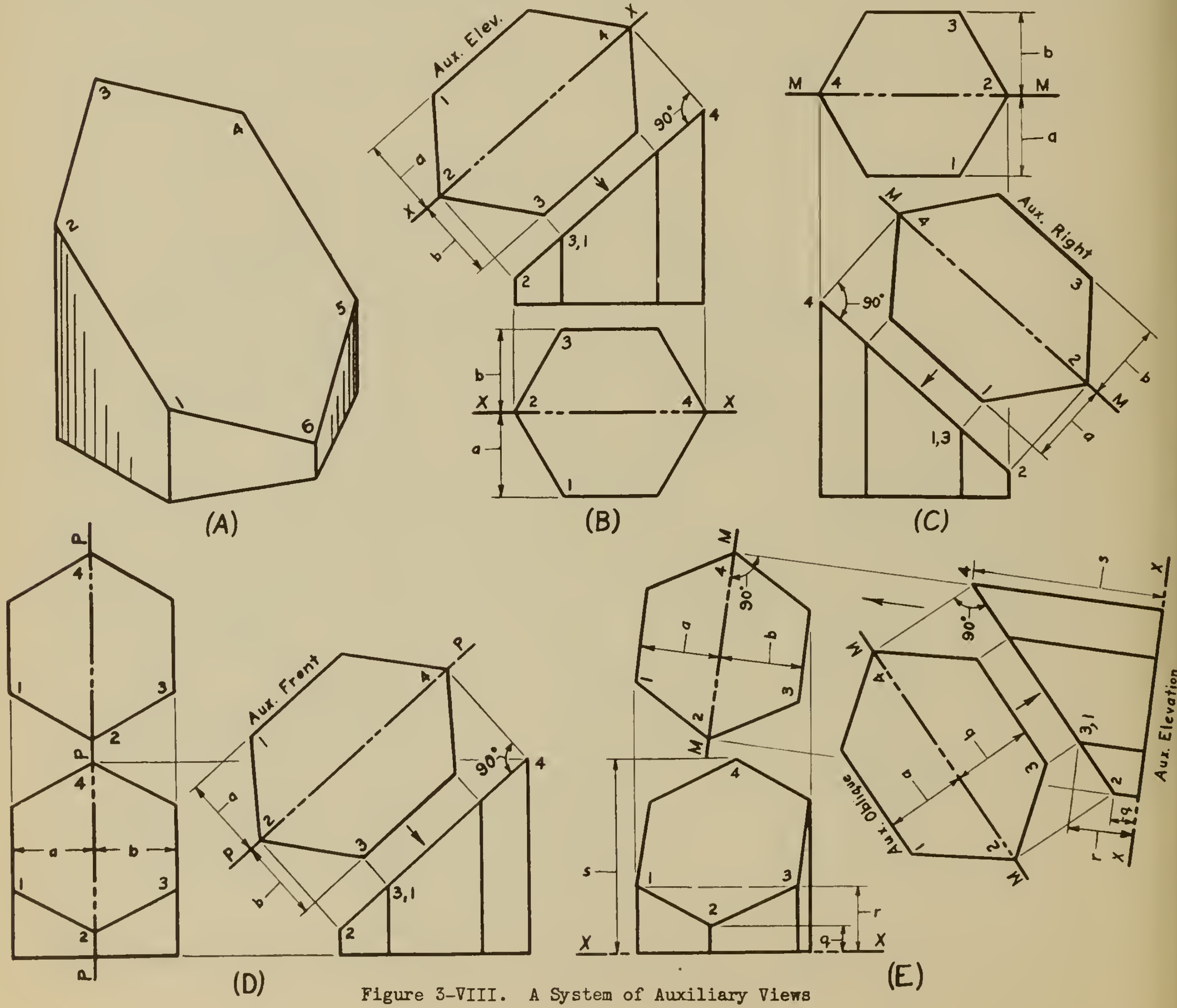

Figure 3-VIII. A System of Auxiliary Views

the object is represented in pictorial. Position (B) shows an auxiliary elevation of the truncated face. Reference plane X-X passes through points 2 and 4 in the front and auxiliary views. Points 1 and 2 are distances a and b, respectively, from the plane in both views.

The auxiliary right and auxiliary front are shown in positions (C) and (D), respectively. Distances a and b in the auxiliaries are obtained as illustrated and described above. The auxiliary oblique is drawn in position (E). It should be noticed that an auxiliary elevation is first obtained in (E) and the truncated face shown as a line before the auxiliary oblique is drawn. Since an auxiliary elevation is taken in a horizontal direction and since it is necessary for the line of sight to lie in the inclined face in order to show the face as a line, 3-1 was chosen as the direction of sight in obtaining the auxiliary elevation. The oblique is then taken off the auxiliary elevation in a direction at right angle to face 1-2-3-4, which is seen as a line in the elevation. All four views are normal (true) views of the truncated face and are projected (at an angle of 90°) off the view which shows this truncated face as a line.

Succeeding articles describe more in detail the different types of auxiliary views.

3-VIII. Auxiliary Elevation. The observer of the auxiliary elevation Figure 4-VIII, is looking at right angles to the elevation dimension, h. Therefore h and all dimensions parallel to h will be seen in true length. These dimensions can be obtained from either the front or side views as illustrated. The other two rectangular dimensions, width and depth, are not shown in true length in

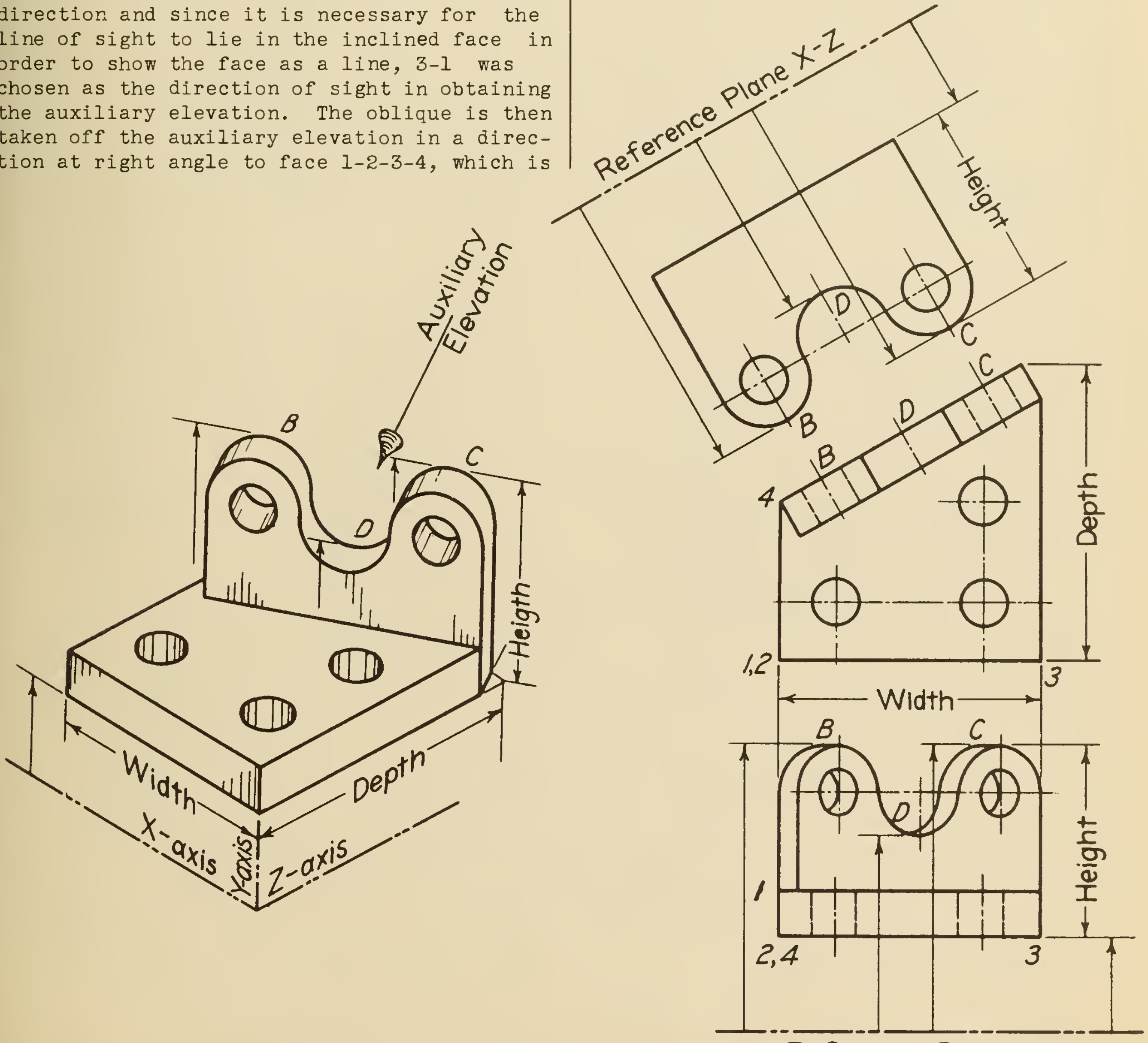

Figure 4-VIII. Auxiliary Elevation

the auxiliary. True dimensions (parallel to the height) are taken from the top view as shown, by drawing rays perpendicular to the X-Z reference plane and parallel to the auxiliary surface BCD. By use of the dividers, the distances that points B, C, and D are from the X-Z plane are taken from the front view, the corresponding rays are followed to the auxiliary, and from the X-Z plane in the auxiliary, these distances are laid off on their respective rays, measuring toward the top view. The face BCD is shown in true area and shape in the auxiliary. The entire object is not drawn.

4-VIII. Auxiliary Right or Left. The observer of the auxiliary right or left, Figure 5-VIII, is looking at right angles to the depth dimension, d. Therefore, d and all dimensions parallel to d will be seen in true length. These dimensions can be obtained from either the top or side views as illustrated. The auxiliary right is here shown. The auxiliary left occupies a similar position to the left of the front view.

Surface ABC is an edge view in the front, i.e., parallel to the front rays, and is therefore a line in the front view. The observer is looking directly into surface ABC in order to secure a true description of that surface. Some convenient reference line must be located either in the top or side view--depending upon the view from which the dimensions are to be taken--and then similarly located in the auxiliary view. Coordinate plane X-Y was chosen from which to take dimensions. Measurements were taken from X-Y in the top to the various points as shown and then laid off on the corresponding rays in the auxiliary by measuring along the ray from X-Y toward the front view. To illustrate: By the use of the dividers, take the distance that point 3 is from X-Y in the top view by measuring along the ray to point 3. Follow the ray to the front view. Turn and follow along the same ray until X-Y in the auxiliary is crossed. Lay off, along the ray just followed, the distance taken from the top by measuring from X-Y toward the front. Other points are located similarly. Locate a convenient number of points on the curve 1-2-3 in the top or side view. Then by the method just described draw all point in the auxiliary

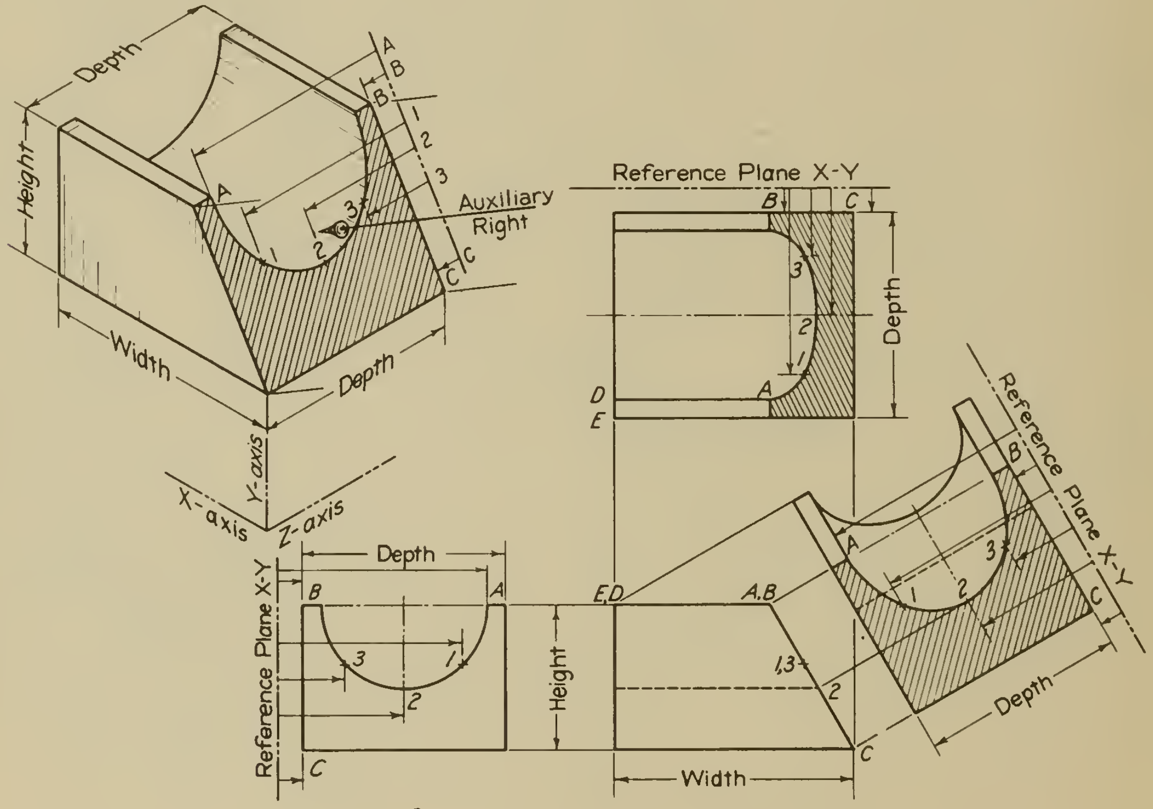

Figure 5-VIII. Auxiliary Right

and connect them by means of the irregular curve.

5-VIII. Auxiliary Front or Rear. The observer of the auxiliary front or rear, Figure 6-VIII, is looking at right angles to the width dimension, w. Therefore w and all dimensions parallel to w will be seen in true length. These dimensions can be obtained from either the front or top views as illustrated. The auxiliary front is here shown. The auxiliary rear occupies a similar position to the left of the side view. To locate points in the auxiliary: Take measurements from Z-Y, Figure 6-VIII, in the front view to a point, say B, by the use of the dividers. Follow ray B to the left side and then to the auxiliary. Lay off on this ray the distance taken in the front view by measuring from Z-Y toward the left side view. It is evident that reference Z-Y should be established first. The entire object is shown but only surface ABE is seen in true area and shape.

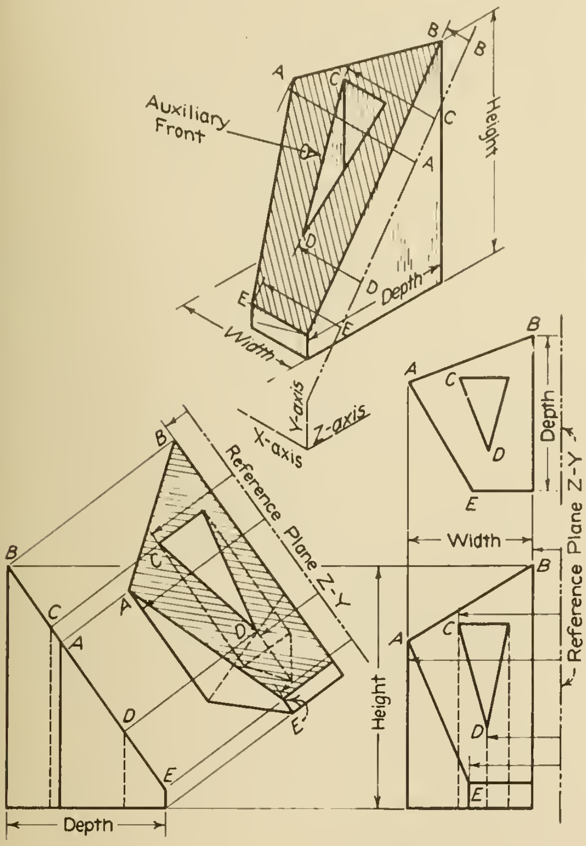

Figure 6-VIII. Auxiliary Front

6-VIII. Auxiliary Oblique. The observer of the auxiliary oblique is standing in an oblique position when the object is viewed, Figures 1-VIII and 7-VIII. The view taken from an oblique position is called an auxiliary oblique. None of the rectangular dimensions shown in the principal views can be seen in true length in the auxiliary oblique. The roof view of the entrance portal is an auxiliary oblique, Figure 7-VIII. Dimension m is in true length and is obtained two views back, i.e., the plan view, and parallel to the auxiliary rays.

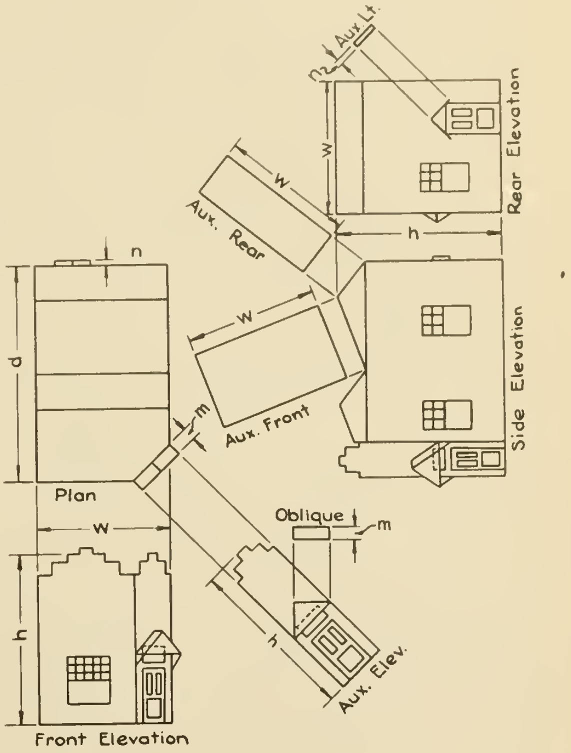

Figure 7-VIII. Some Structural Features

AB, Figure 8-VIII on the following page, is the center line of a rectangular beam in oblique position. Therefore, AB is an oblique line. The beam is one of several supports for an inclined conveyor. The conveyor is intersected by two parallel landing floors which make angles of 15 degrees with a horizontal surface, plane X-Z. The broader face of the beam is vertical. The location of the center line is given, i.e., B is 22'-6" to the right of A, drawing (1); it is 15'-0" below A; and is 12'-6" behind A. Required: front and top views of the beam.

A view looking along AB must first be obtained. Such a view can be drawn by taking an auxiliary oblique in the direction of AB. That is, AB will be a point in the oblique. In order to do this, an auxiliary view

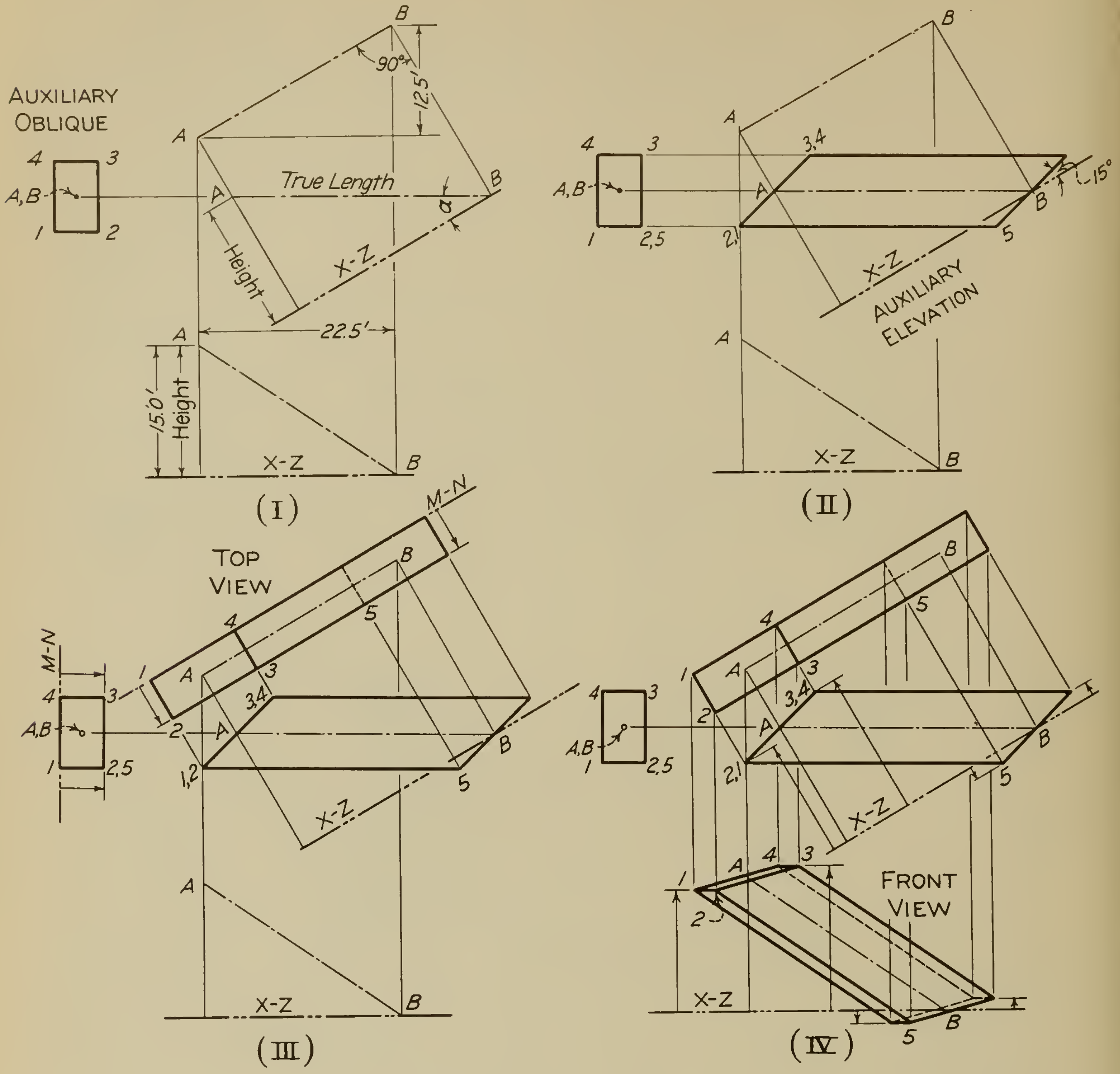

Figure 8-VIII. Progressive Drawings of Rectangular Beam in Oblique Position

perpendicular to AB must first be obtained. If the visual rays make an angle of 90 degrees with AB, the line will be in true length, drawing (I). An auxiliary elevation is used here. The oblique is taken in the direction of AB off the auxiliary elevation, which will show AB as a point. A right section of the beam is shown. Since the broader face is to be vertical the shorter edge, 1-2, will be horizontal or parallel to the rays, as indicated. The next step in the progression is to draw the auxiliary elevation, drawing (II). Rays are drawn from the oblique back to the elevation drawing parallel to the ray coming from AB. Since the two ends are perpendicular to the vertical faces of the beam, they will appear as a line in the elevation. That is, surface 1-2-3-4 is an edge view or receding surface and will therefore be seen as a line. Surface 2-3-5 is perpendicular to surface 1-2-3, perpendicular to the line of vision in the auxiliary elevation, and will therefore be shown in actual area and shape, i.e., a normal surface. Since X-Z and the ends of the beam are edge views, the required 15-degree angle between them can be constructed as shown and the auxiliary elevation completed. After two drawings of an object are completed, as many views as desired can be obtained. The top view is next drawn, part (III). It is taken off the auxiliary elevation, parallel to the rays coming from AB. The missing dimensions, parallel to the rays, can be obtained from the second view back, the oblique, by taking measurements from reference M-N parallel to the oblique rays and laying them off parallel to the top rays, measuring M-N in the top. It should be noticed that the reference plane M-N coincides with a surface of the beam. The front view can now be drawn from the top as indicated in (IV). The missing dimensions (elevation dimensions) can be obtained from the second view back (auxiliary elevation). Measurements are taken from X-Z parallel to the rays and laid off from X-Z in the front parallel to the rays. Reference surfaces (or reference lines) are always drawn perpendicular to the visual rays.

7-VIII. Structural Drafting Room Practice designates the principal views as plan and elevations, Figures 2-VIII and 7-VIII, i.e., plan, front elevation, side elevation, etc. It should be noticed that all elevation views are taken off the plan view, except the rear elevation, which is usually placed adjacent to a side elevation. Figure 7-VIII is a line drawing of the "Corner Drug Store" with a saw-tooth roof. The front entrance is at the corner. There is also a rear entrance. The various auxiliary views show these different features.

8-VIII. Rules for Drawing Auxiliary Views. The following rules are prepared for the purpose of aiding the beginner in orientating himself while laying out and taking measurements for auxiliary views:

(1) Establish the reference plane from which measurements are to be taken. In the case of the auxiliary elevation, for instance, it will be a horizontal plane and therefore a line in the front or side views, as line X-Z, Figure 2-VIII. For an auxiliary right it will be a line in the top or side views, as line X-Y, Figure 4-VIII. And for an auxiliary front, the line will be seen in the front and top views, as line Z-Y, Figure 6-VIII. In the case of an auxiliary oblique, the line will be seen in the principal view from which the auxiliary elevation, right, or front was taken in drawing the oblique. If an auxiliary elevation were to be used, the line would be M-N, Figure 8-VIII. In all cases the reference lines are located perpendicular to the visual rays. A corresponding reference line is then located in the auxiliary view and perpendicular to the rays.

(2) The missing measurements for drawing auxiliary views are always found parallel to the visual rays two views back. To draw an auxiliary elevation: Go to the first view (top), then turn and go to the second (either the front or the side), and the measurements sought will be parallel to the rays in that view. This rule will also hold in the case of principal views.

(3) It is often difficult for a beginner to determine which way an auxiliary line should be sloped, for instance, which side of the reference plane X-Z should point A be located, in the auxiliary elevation, Figure 8-VIII (I). Three views must be considered. One is a central view. In this case the front, top, and auxiliary views are used. The top view is the central view. Look across the front view into the central view (top). Point A in the front is farther from the observer than is point B. Look across the auxiliary view into the central view (top). Point A in the auxiliary should be farther from the observer than point B.

9-VIII. Direction of Lines. The directions of straight lines may be stated as (1) oblique, (2) frontal, . (3) horizontal, (4) profile, (5) vertical, and are described as follows:

(1) Each point in an oblique line is above or below, to the right or left of, in front or behind every other point in the line, (I) and IV), Figure 9-VIII.

(2) All points in a frontal line are equidistant from an observer of the front view (II), Figure 9-VIII.

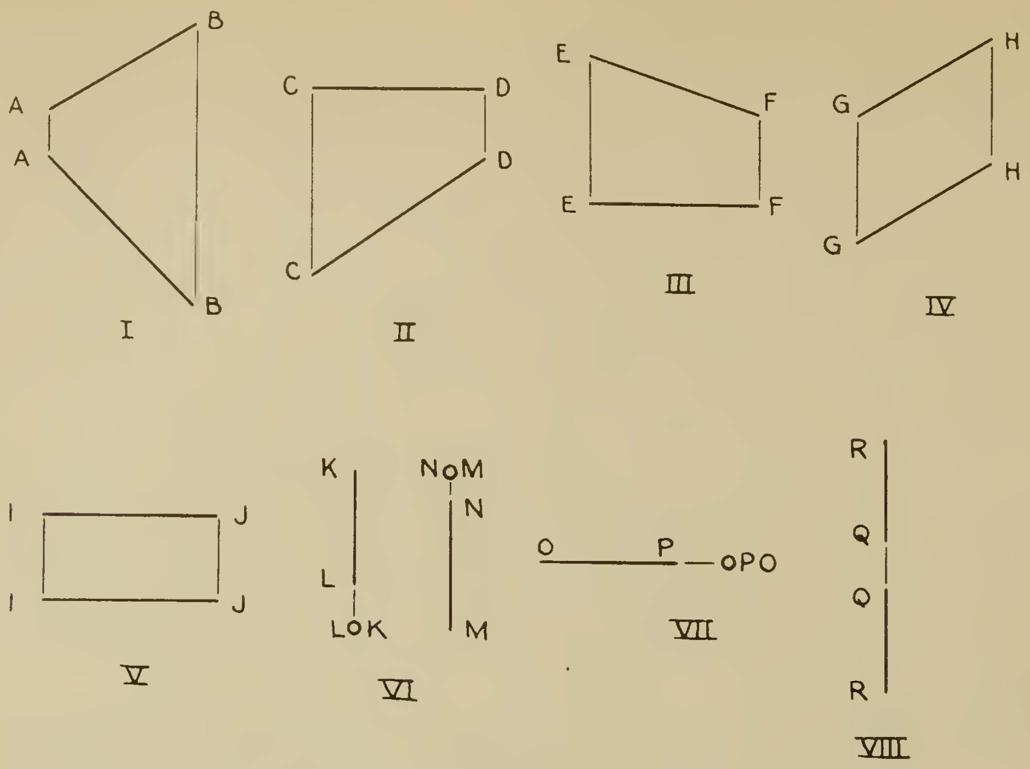

Figure 9-VIII. Direction of Lines

(3) In a horizontal line all points are at the same elevation, i.e., all points are equidistant from an observer of the top view (III), Figure 9-VIII.

(4) Each point in a profile line is equidistant from an observer of a side view (VIII), Figure 9-VIII.

(5) A vertical line is seen as a point in the top view. It is a frontal-profile line. The frontal and profile lines are special cases of the vertical line. See MN in (VI), Figure 9-VIII.

10-VIII. Direction of Surfaces. The direction of plane surfaces (or planes) may be stated as: (1) oblique, (2) frontal, (3) horizontal, (4) profile, (5) vertical, (6) normal, (7) receding. They are described as follows:

(1) Each point in an oblique surface is above or below, to the right or left of, in front or behind every other point in the surface, surface 1-2-3-4 (IV), Figure 8-VIII.

(2) All points in a frontal surface are equidistant from an observer of the front view, 1-2-3, Figure 4-VIII. It is seen as a line in the top and side views.

(3) In a horizontal surface, all points are at the same elevation. Also, all points are equidistant from an observer of the top view, ADE, Figure 5-VIII. It is seen as a line in the front and side views.

(4) Each point in a profile surface is equidistant from an observer of a side view, surface BC, Figure 5-VIII. It is seen as a line in the top and front views.

(5) A vertical surface is seen as a line in the top view. The frontal and profile surfaces are special cases of the vertical surface. Surface BCD, Figure 4-VIII, is vertical, 1-2-3 is frontal, and 1-2-4 is a profile surface.

(6) A surface appearing in actual size and shape is called a normal surface, as ABE, Figure 6-VIII, auxiliary view; and ABC, Figure 5-VIII, auxiliary view.

(7) When a surface appears as a line in a view (when it is parallel to the visual rays) it is said to be an edge view or a receding surface in that view, as ABC, front view, Figure 5-VIII; 1-2-3, auxiliary elevation, Figure 8-VIII (IV).

## EXERCISES

11-VIII. The following exercises in auxiliary views may be drawn in a space 51/2" x 6 1/2", except where noted. Unless instructed differently, all dimensions should be omitted. Auxiliary views of only inclined faces or surfaces should be drawn, unless instructed otherwise.

## Group 1-VIII. Primary Auxiliaries

1. Reproduce the front and top views of Figure 10-VIII. Scale 1/4" = 1". Add an auxiliary elevation drawing of the part indicated. Leave sufficient space between the front and top views to admit the auxiliary.
2. Copy the top view and the auxiliary elevation given in Figure 11-VIII. Scale 3/8" = 1". Draw next the front view in the proper position.

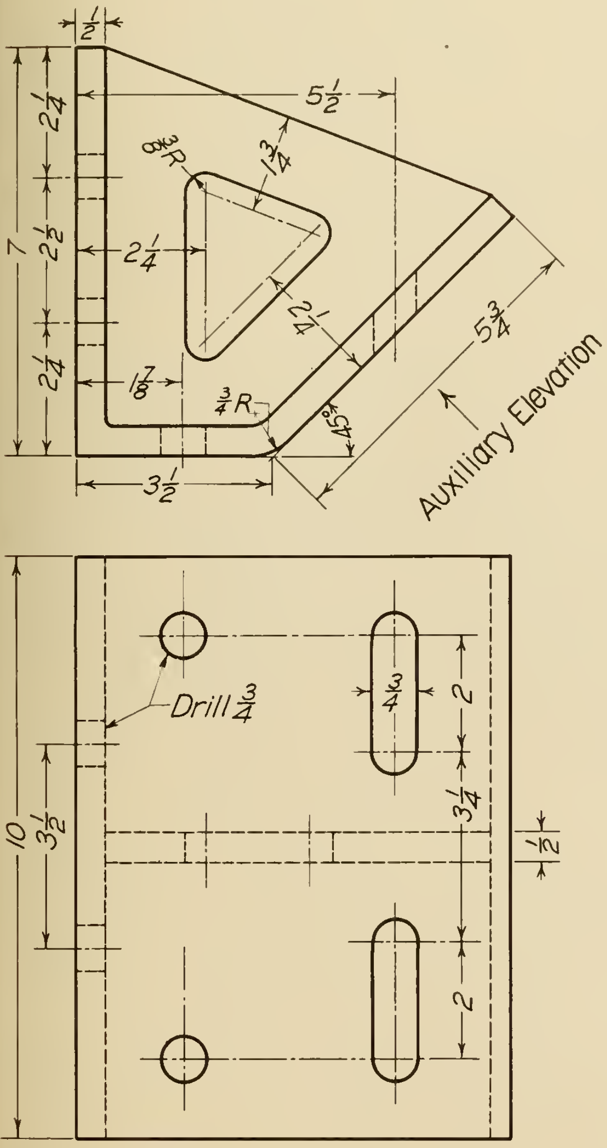

Figure 10-VIII. Stop Plate

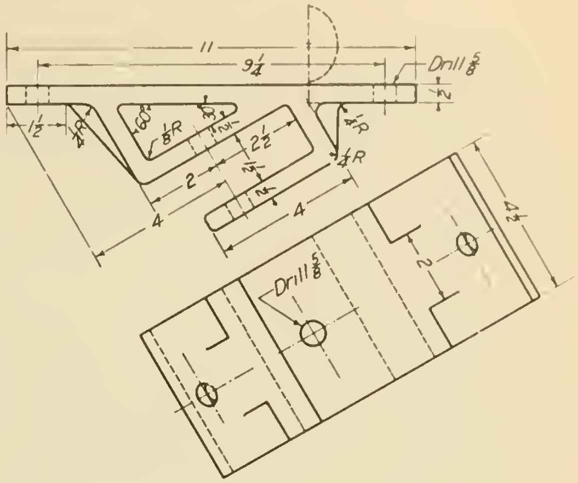

Figure 11-VIII. Sheave Stand

3. Redraw the front and top views of Figure 12-VIII. Then draw an auxiliary right of the inclined face as indicated. Leave sufficient space between the principal views to admit a part of the auxiliary view. Scale 1/2" = 1". Radii marked "5/8 R" are not seen as true length dimensions, which is a violation of good practice. It was necessary to make the exception here.

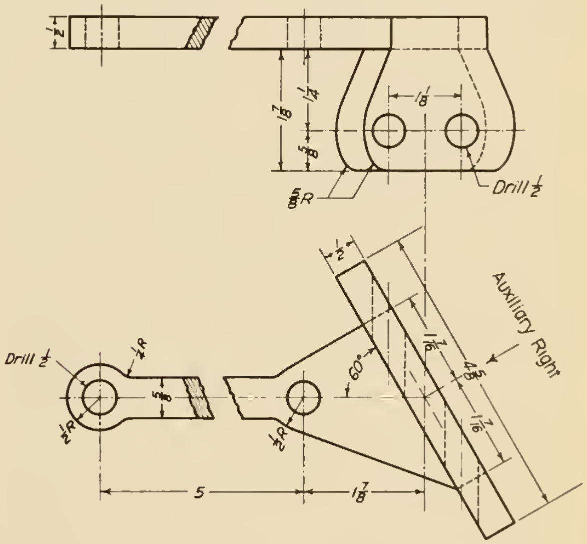

Figure 12-VIII. Chain Link

4. Copy the front and top views of Figure 13-VIII. Scale 1/2" = 1". Then draw the auxiliary left of the inclined base as

indicated. Leave sufficient space between the principal views to admit a part of the auxiliary view. Use a double space.

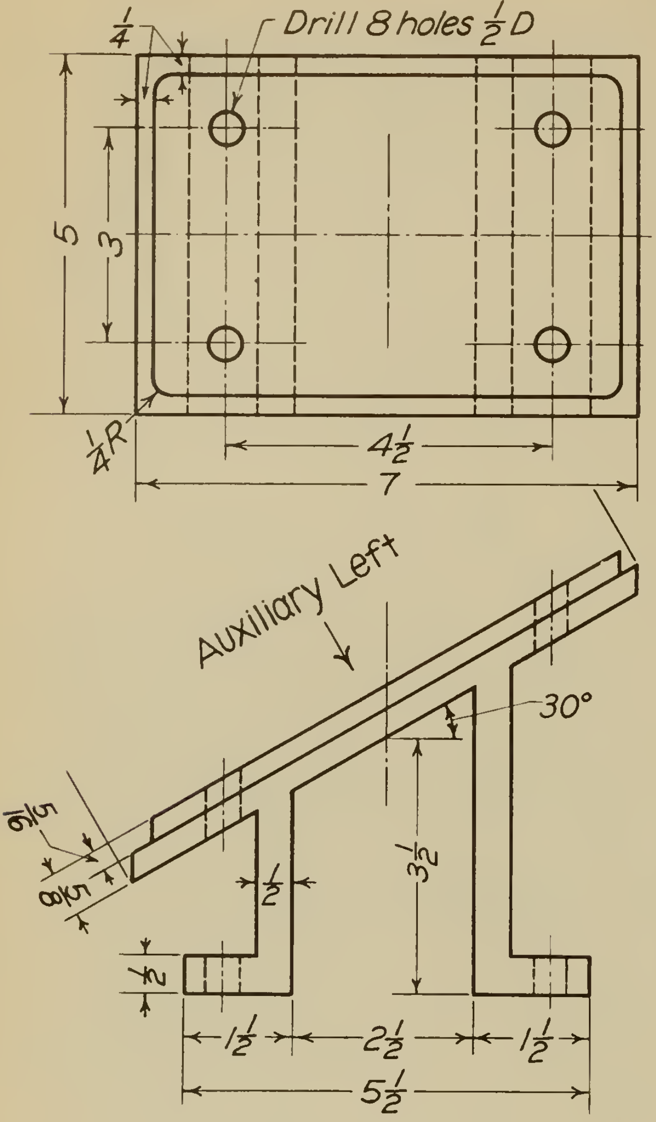

Figure 13-VIII. Press Bed

5. Redraw the right side and the auxiliary front views shown in Figure 14-VIII. Scale 1/8" = 1". Then draw the front view in proper position.
6. Reproduce the front and left side views of Figure 15-VIII. Scale 1/2" = 1". Draw next the auxiliary rear of both sloping parts as indicated. A double space will be required.
7. Scale 1/2" = 1". Make an auxiliary drawing of the inclined face of the shaft box of Figure 16-VIII on the following page. This face makes an angle of 30° with the front (vertical) face. Show also the necessary principal views.

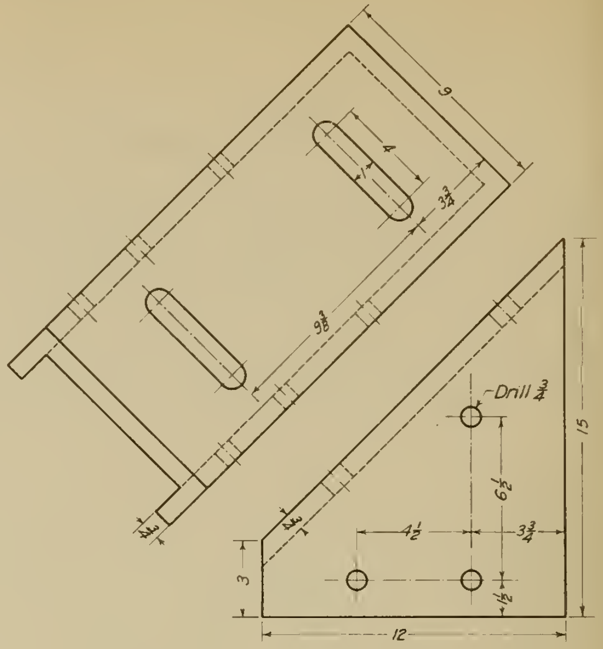

Figure 14-VIII. Idler Support

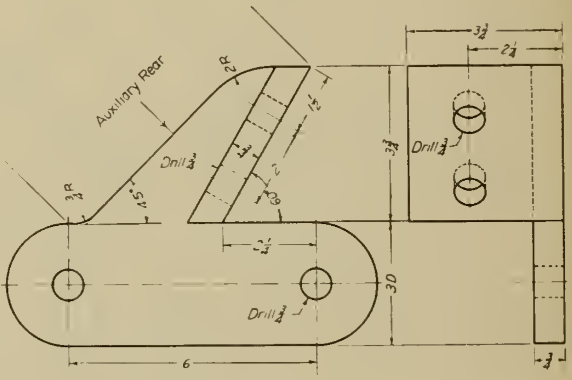

Figure 15-VIII. Chain Link

8-12. Scale to be selected. Five angle blocks at joints $L_0$, $L_1$, $L_2$, $U_2$, and $U_3$ of Figure 59-XVII. Draw the front and top views of one of the angle blocks of the Pratt roof truss described above. Then draw an auxiliary view of the inclined face against which the tension rod washer fits, or the face against which the 6" x 8" timber rests. Supply any missing details. The bottom views are to be omitted and top views drawn instead. Drawings at joint $U_3$ are line sketches not drawn to a scale.

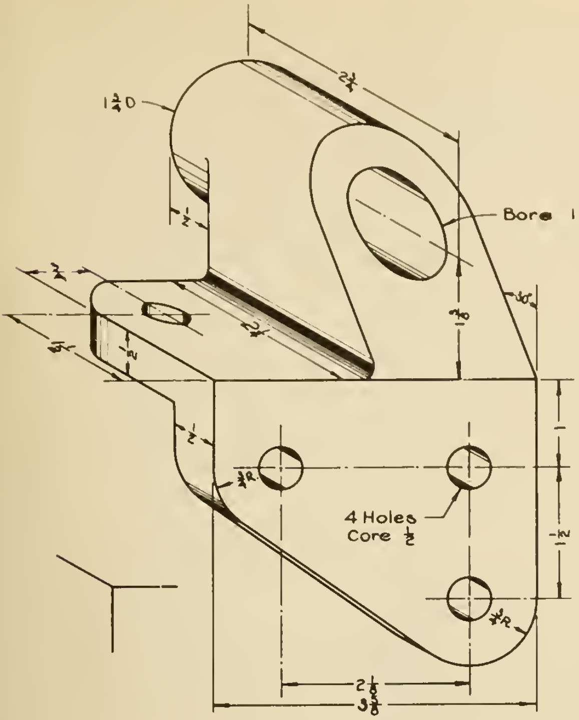

Figure 16-VIII. Special Shaft Box

## Group 2-VIII. Secondary Auxiliaries

1. Copy the front and top views of Figure 17-VIII. A double space for this problem will be required. Scale 1/4" = 1'-0". Draw next the additional views which will give true representations of beam AC and brace BC. Draw auxiliary oblique views (showing right sections) of members AC and BC. The longer edges of each timber will be shown as points in the oblique. Make auxiliary drawings of the beveled faces of brace BC. What is the shortest length of timber from which BC can be cut?
2. Truss layout: Scale 1/4" = 1'-0". Use a double space. (1) Reproduce the drawing of Figure 18-VIII, shown on the following page, a shed truss, and add a plan view. (2) Detail layout: Scale 1" = 1'-0". Make dimensional drawings of each timber of the truss. The draftsman should supply the missing dimensions for the various details.
3. Same as Exercise 2, above, except the truss makes an angle of 30° with a frontal plane and extends back and to the right.
4. In the center of the problem space, draw a 5 1/4" square. Measurements which will locate points A and B are to be taken from the lower left-hand corner of the square. Line AB is the axis of a right hexagonal prism in oblique position. The front view of A is 3 1/2" to the right and up 1 1/2"; the top view is 2 1/8" above the front view. The front view of B is 4 1/2" to the right and up 3/4"; the top view is 3 3/8" above the front view. The hexagonal bases of the prism are inscribed in a 1" circle. Two sides of the hexagon in each base are parallel to a horizontal plane. Draw the front, top, left side, auxiliary elevation, and auxiliary oblique views of the prism. For order of procedure, see Figure 8-VIII. Erase the 5 1/4" square.

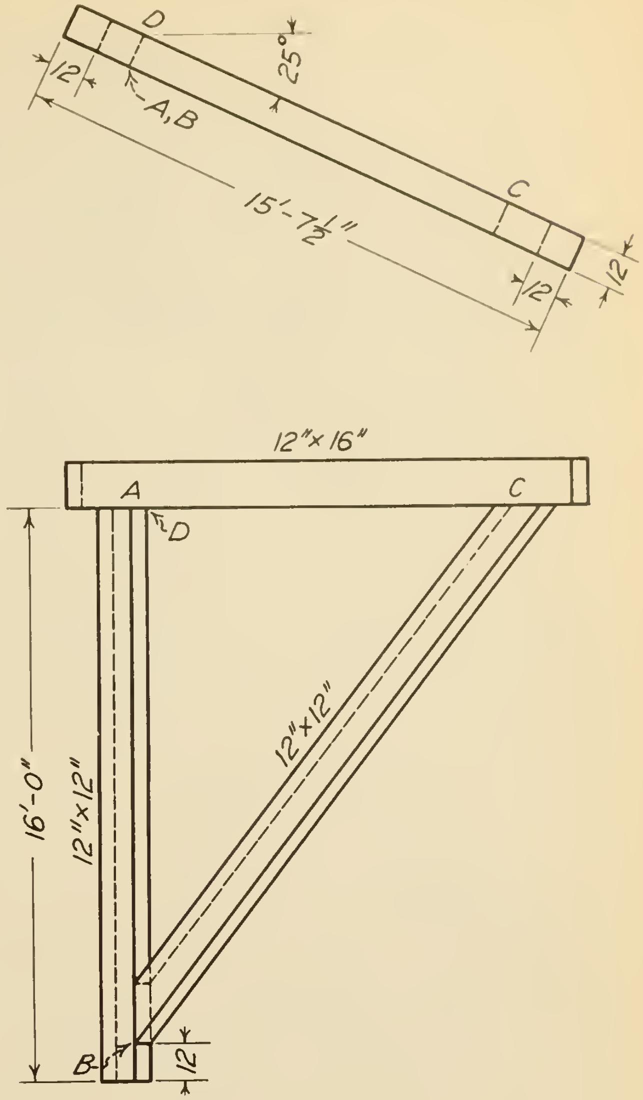

Figure 17-VIII. Timber Brace and Beam

5. Scale 1/4" = 1'-0". A double space will be required. Figure 19-VIII, on the following page, concrete foundation for timber

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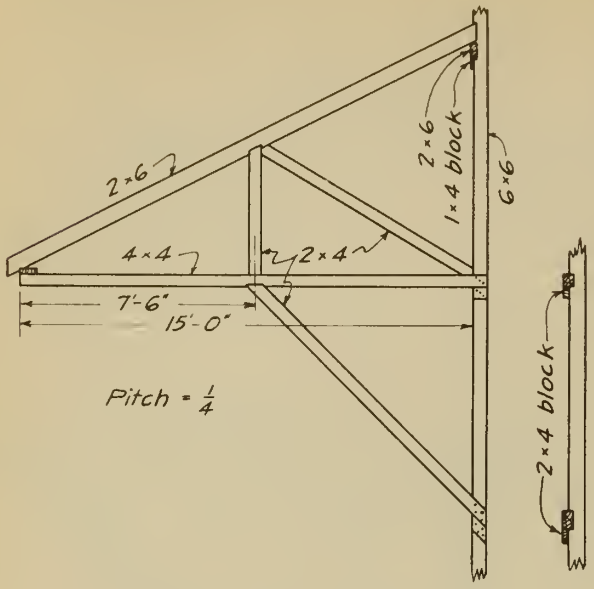

Figure 18-VIII. Shed Truss

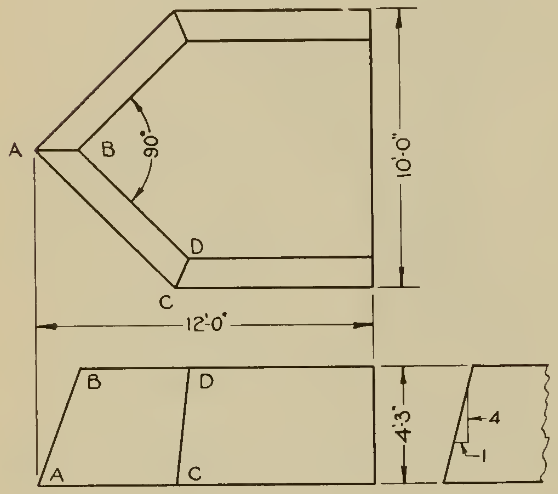

Figure 19-VIII. Foundation Footing

bridge bent. Reproduce the principal views as shown. Obtain an auxiliary view showing the true size and shape of the oblique surface ABCD. Give the area in square feet.

Hint: A primary auxiliary must first be obtained showing ABCD as a line. The visual rays must lie in, or coincide with, ABCD when obtaining this view. Then a secondary auxiliary must be secured looking at right angles to the edge view of the primary auxiliary.

6. Scale 1" = 1'-0". A double space will be required. Figure 20-VIII, top end of one of the vertical timber supports of a bin. Reproduce the principal views as shown. What is the area in square feet of surfaces (1) ABC, (2) DEF, and (3) ACDE? Read exercise 5-2-VIII for further descriptive matter and hint for solution.

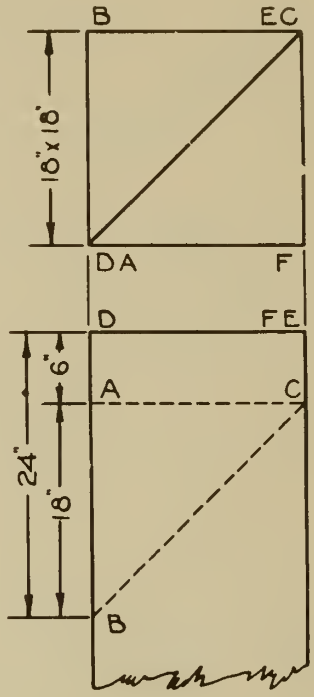

Figure 20-VIII. Bin Support

7. Scale 1/2" = 1'-0". A double space will be necessary. Figure 21-VIII, on the following page, a special manhole at the intersection of two "blind" streets. What is the area in square feet of the two inlet surfaces ABC and BCD? Read exercise 5-2-VIII for further descriptive matter and hint for solution.
8. Scale 1/4" = 1'-0". Figure 17-VIII, timber brace and beam. Make an auxiliary view, in addition to the two principal views shown, which will represent all three members of the beam in a normal view.

### Group 3-VIII. Miscellaneous Exercises

1. Scale 1" = 1". Space 8" x 8". Figure 22-VIII on the following page. Draw two principal views and an auxiliary view of the angle block.

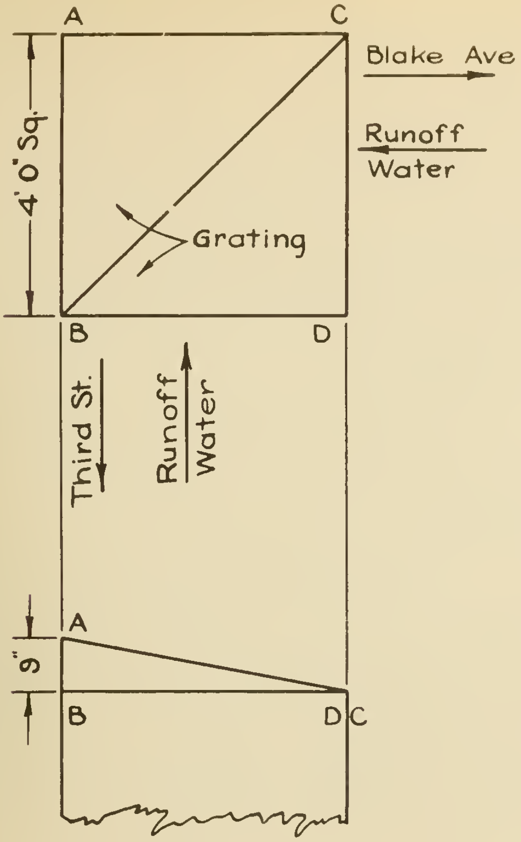

Figure 21-VIII. Special Manhole

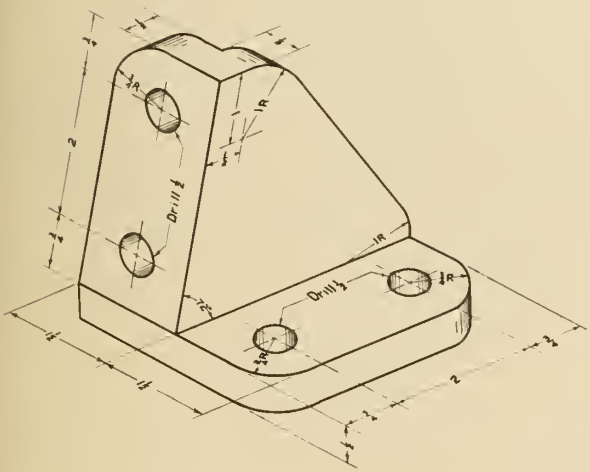

Figure 22-VIII. Angle Block

2. Scale 3/4" = 1". Space 8" x 8". Figure 23-VIII. Draw two principal views and an auxiliary view of the base support.

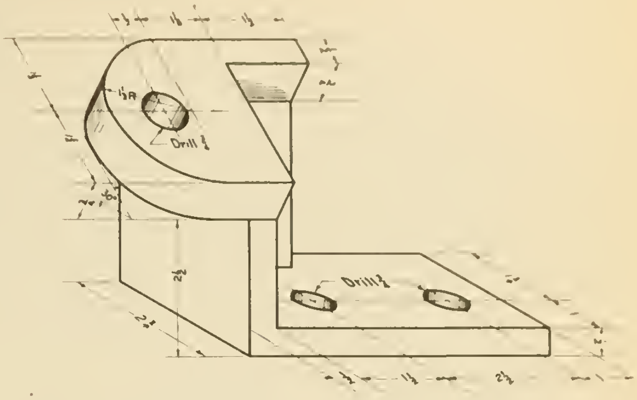

Figure 23-VIII. Base Support

3. Scale 3/4" = 1". Space 8" x 8". Figure 24-VIII. Draw two principal views and an auxiliary view of the bearing block.

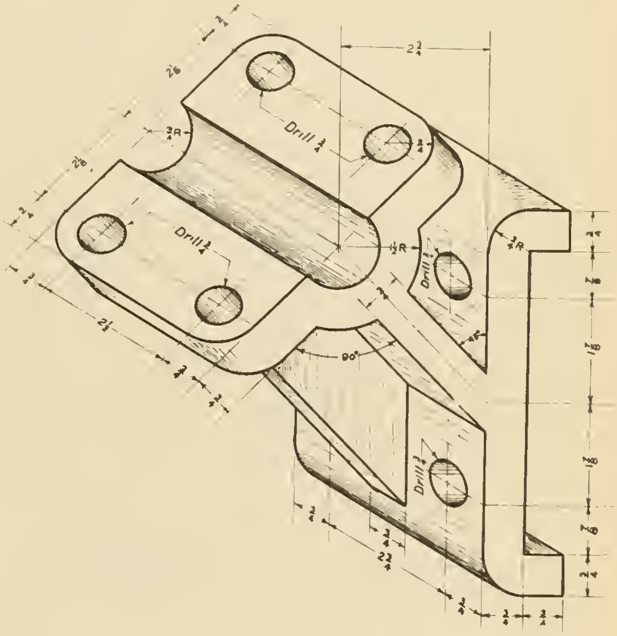

Figure 24-VIII. Bearing Block

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# CHAPTER IX

## REVOLUTION

1-IX. There are two methods which can be used to obtain true lengths and normal views of objects or to show an object in simple position, when these objects are in oblique position. They are: (1) Auxiliary view method, (2) Revolution method. The former was described in Chapter VIII, while the principles of revolution will be outlined in this chapter.

In the auxiliary view method the observer shifts position for each view, while in revolutions the observer remains in a fixed position, and the object is revolved into a new position for each view.

2-IX. Principles of Revolution. The following fundamental principles of revolution should be mastered to give the student a clear conception of what is taking place in space when an object is being revolved:

1. The view of an object which shows the axis of revolution as a point will change only in position but not in size or shape. In this view only will the true angle of revolution be seen.

2. All dimensions parallel to the axis of revolution will remain unchanged in other views.

3. A point revolving about an axis lies in a plane perpendicular to the axis. A view showing the axis as a point will show the path of the point as a circle. In all views taken at right angles to the axis the circle will be seen as a line.

3-IX. Revolution of a Solid. The clip of Figure 1-IX, I, is shown in simple position. It is desired to revolve the object from position I forward through angle a. The axis of revolution is therefore perpendicular to the profile, in which view will be seen the true angle a. The side view of position I is transferred as the new side view of position II, revolved through angle a, and

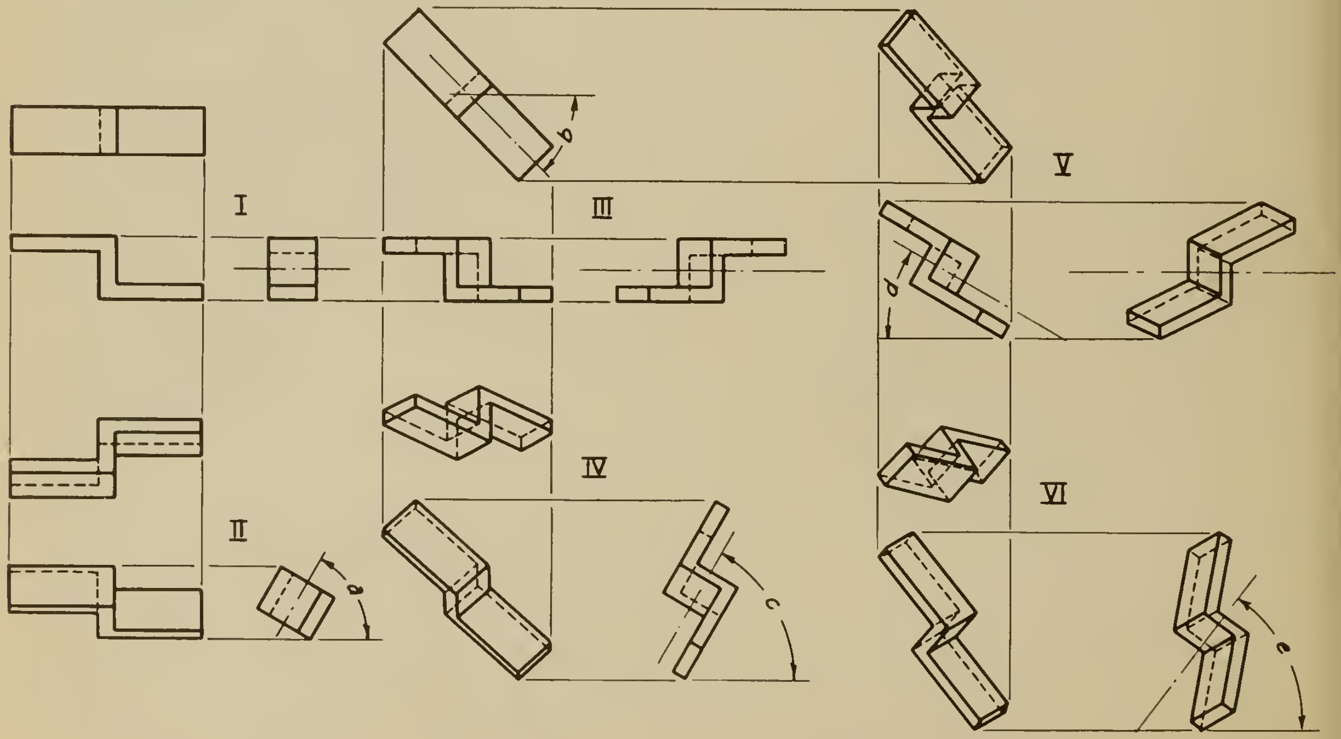


Figure 1-IX. A Clip Revolved into Various Positions

elevation dimensions are transferred to the left by drawing horizontal lines. The dimensions parallel to the axis are found in the front or top views and can be transferred to position II by drawing vertical rays. Thus the front view of position II is completed and the top view can now be drawn.

The clip is next revolved from position I about an axis perpendicular to a horizontal plane. The top view of position I is transferred to position III as the new top view and revolved clockwise through an angle b. Dimensions parallel to the axis are transferred downward from the top view of III while the dimensions perpendicular to the axis can be transferred to the right from the elevation drawings of I, thus forming the front view of III. The side view of III can now be drawn.

To draw the object in the remaining positions: (1) Revolve from position III about a profile axis, counterclockwise, through an angle c. Transfer the side view of III to the side view of IV. Revolve counterclockwise through an angle c. Complete the front and top views as described above and as shown in the drawing. (2) In position V, the axis is perpendicular to a frontal plane and the angle d is generated clockwise. The remaining steps are self-evident. (3) In position VI the axis is perpendicular to a profile plane, and the angle e is generated counterclockwise.

4-IX. Revolution of a Point. To revolve point P about an oblique axis AB, clockwise through an angle of 165°, Figure 2-IX:

Obtain a true length view of AB (auxiliary elevation in this case) and show P in the same drawing. Obtain an auxiliary oblique of the system, showing AB as a point. With AB as a center, revolve P clockwise through 165° and call the new position of the point P'. Show P' in all views. The various steps are self-evident.

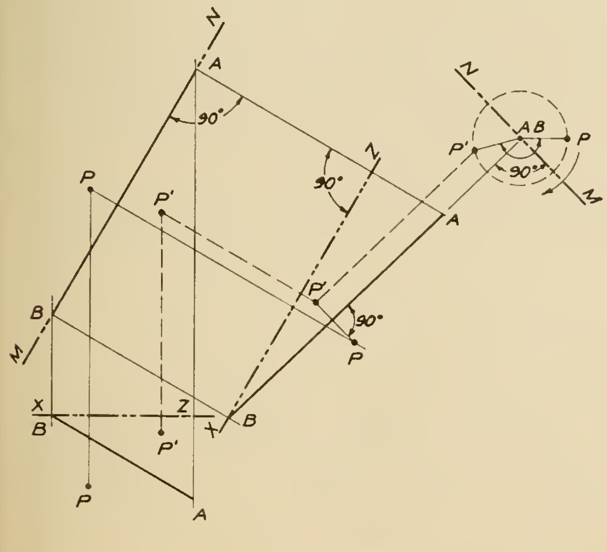


**Figure 2-IX.** Revolution of a Point

5-IX. Revolution of a Line. To revolve a line into true length:

Consider line AC an element of a cone. Part I, Figure 3-IX, shows the cone and element in pictorial. Part II is the orthographic representation. The axis of revolution is a point at A in the top view. Therefore it is a vertical line and in true length in the front view. Point C describes a circle in the top view which is a line (base of the cone) in the front view and perpendicular to the axis of revolution. As C takes various positions on the circle, D, E, F, etc., in the top view it will oscillate back and forth on a line perpendicular to the axis of

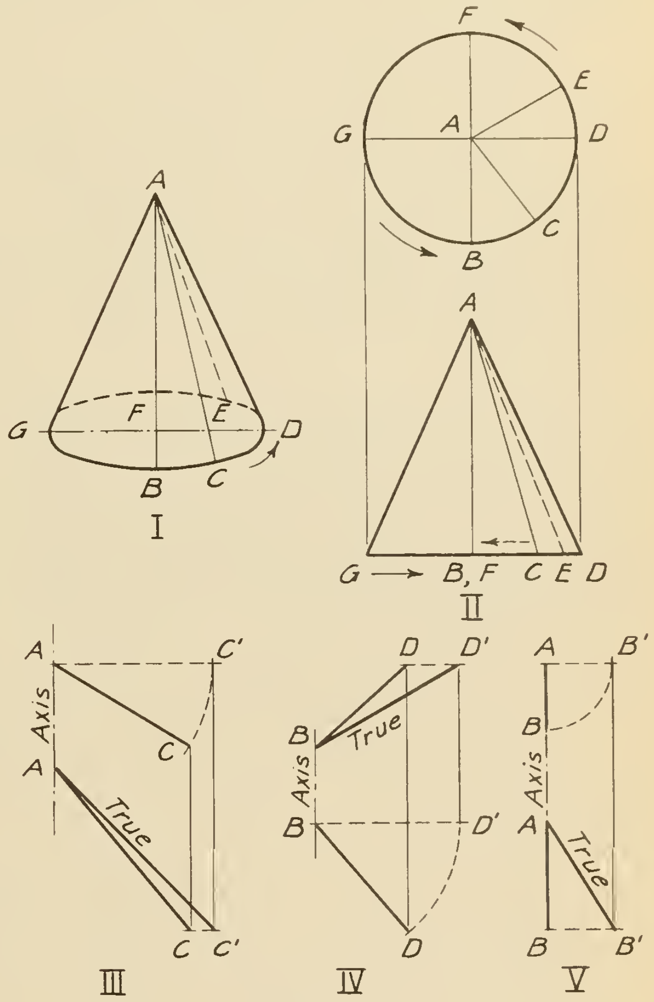


**Figure 3-IX.** Revolution of a Line

revolution. Line AD in the front view is the true length of AC. Therefore AD in the top view will be a level line. To find the true length of AC in the front view, part III, not using a cone:

Draw a level line through A in the top views. With A as a center and AC as a radius, sweep an arc cutting this level line, thus locating C'. Through C in the front view draw a level line (perpendicular to the axis of revolution). From C' in the top view draw vertically downward until these horizontal and vertical lines intersect, thus locating C' in the front view. Connect A and C' in the front view, which is the true length of the line, since it is now a frontal line.

Part IV, Figure 3-IX, shows line BD revolved into a horizontal plane by the method described above and is therefore seen in true length in the top view. Line AB, part V, is a profile line revolved into true length in the front view by the method just described.

6-IX. Revolution of a Plane. Oblique plane ABC, Figure 4-IX, has been revolved until it is a normal view in the top and is therefore seen as a horizontal plane. The steps are:

Draw a horizontal axis in the plane, CM. It is a point in the auxiliary elevation. By the method of revolving a point, revolve A and B into a horizontal plane with C, which are points A' and B'. Connect A'B' and C in the top view. (Line A'B' should pass through M.) Thus the true size and shape (normal view) of ABC is obtained.

## EXERCISES

7-IX. The following problems in revolution may be drawn in a space 5 1/2" x 6 1/2" except where noted.

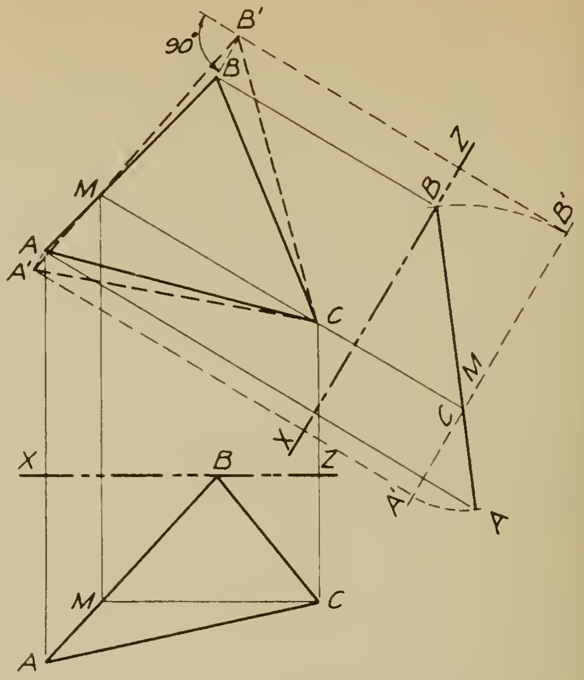


Figure 4-IX. Revolution of a Plane

### Group 1-IX. Revolution of a Simple Solid

1-5. Scale 3/4" = 1". Figure 5-IX, (A), (B), (C), (D), and (E). Reproduce the assigned object which will be position I, Figure 1-IX. Space 8 1/2" x 14". Revolve as indicated below:
(1) From position I about a frontal-horizontal axis, clockwise through 30°.
(2) From position I about a vertical axis counterclockwise through 30°. (3) From position III about a frontal-horizontal axis counterclockwise through 30°. (4) From position III about a horizontal-profile axis clockwise through 30°. (5) From position V about a frontal-horizontal axis clockwise through 30°.

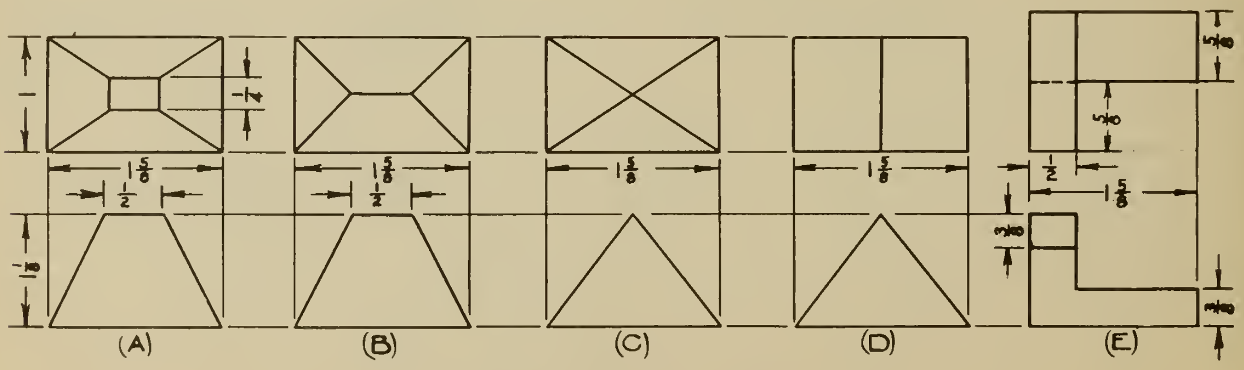


Figure 5-IX. To Revolve a Solid

### Group 2-IX. Revolution of a Point

1-4. Scale 1" = 1". Figure 6-IX, (A), (B), (C), and (D). Coordinate squares = 1/2". Copy the line and point assigned. Revolve the point about the line as an axis, clockwise, through 75°, and show the point in the new position in all views.

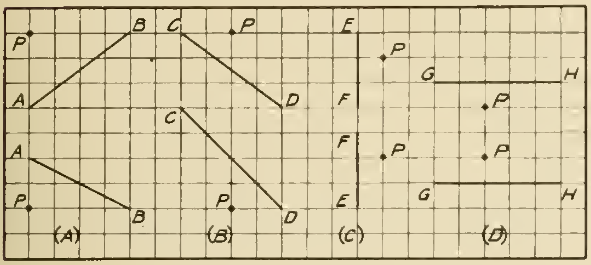


Figure 6-IX. To Revolve a Point

### Group 3-IX. Revolution of a Line

1-4. Scale 1" = 1". Figure 7-IX, (A), (B), (C), and (D). Coordinate squares = 1/2". Copy the line assigned. Revolve into a horizontal plane. Check by revolving into a frontal plane. Give true length of line to nearest 0.01 inch.

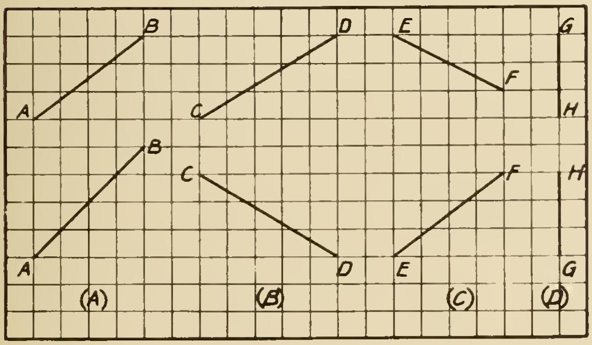


Figure 7-IX. To Revolve a Line

### Group 4-IX. Revolution of a Plane

1-4. Scale 1" = 1". Figure 8-IX, (A), (B), (C), and (D). Coordinate squares = 1/2". Copy the plane assigned and then obtain a normal view of this plane by revolving it into one of the principal planes. Give the area of the plane to the nearest 0.01 square inch.

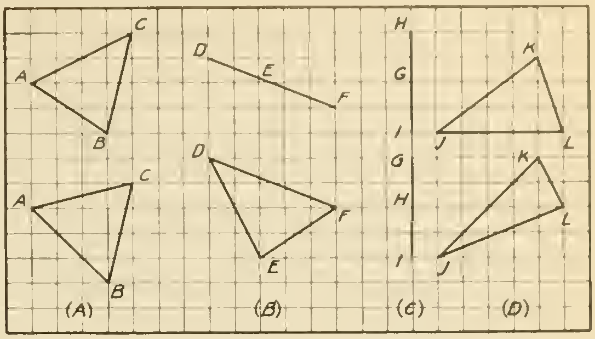


Figure 8-IX. To Revolve a Plane

### Group 5-IX. Size of an Angle

1-4. Scale 1" = 1". Figure 9-IX, (A), (B), (C), and (D). Coordinate squares = 1/2". Copy the angle assigned. Obtain the true size of the angle by revolution and give results to the nearest half-degree.

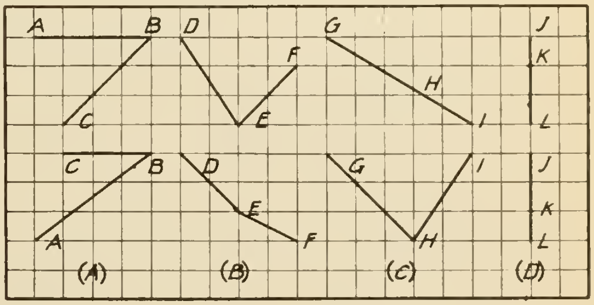


Figure 9-IX. To Measure an Angle

### Group 6-IX. Some Miscellaneous Applications

1-4. Solve Ex. 5, 6, 7, and 8, Gr. 2, Ch. VIII, by revolution.

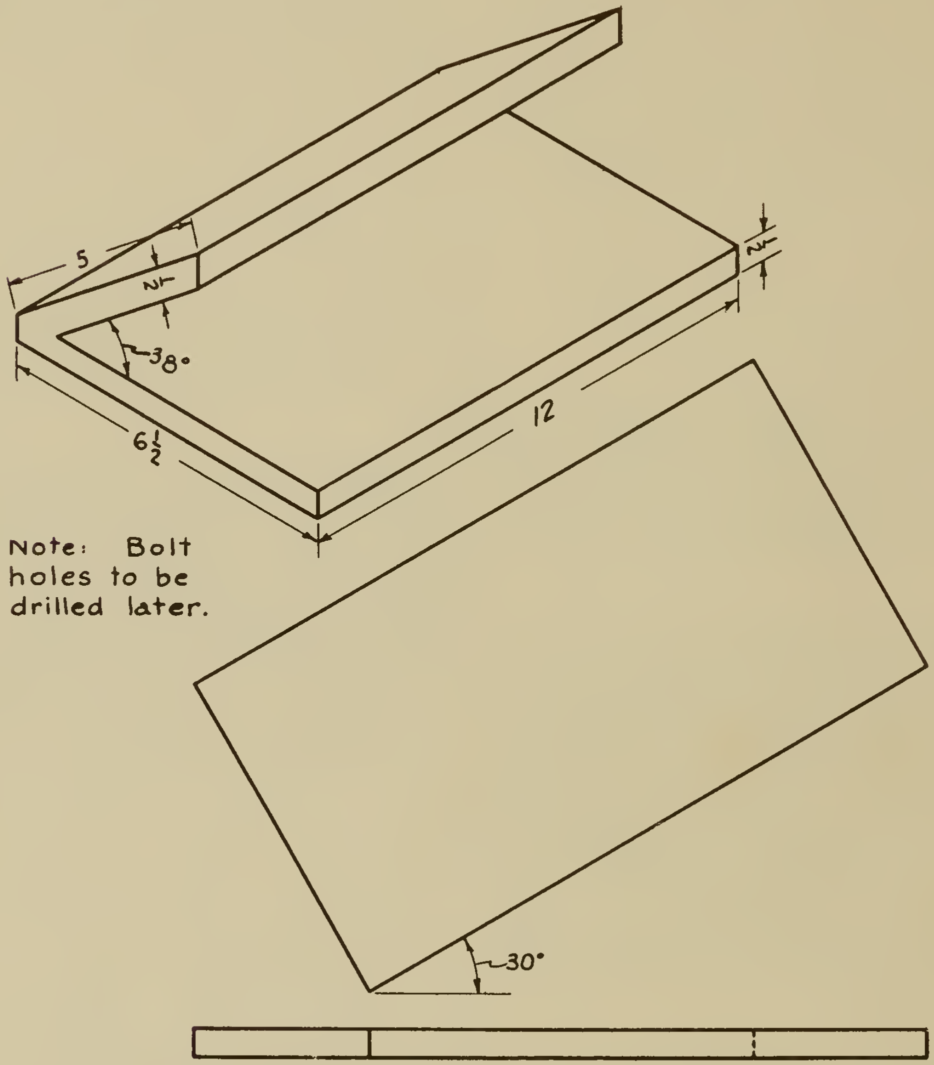
5. Scale 1/4" = 1". Figure 10-IX, on the following page, shows, at the top, a pictorial drawing of an anchor plate (with bolt holes omitted). The two lower drawings show only the base of the plate. The front edge makes an angle of 30° with a frontal plane. Reproduce the front and top views of the base and:

(1) Show the inclined plate properly attached to the base.

(2) Then tilt the entire object forward through 30°, revolving about the

lower front line, 12-inch edge of the base, as an axis.

6. Scale 1" = 1". Draw a tetrahedron with a 1 1/2" equilateral base resting in a horizontal plane. Altitude 2". One edge of the base is a frontal-horizontal line. Call this line AB. Revolve the object about a vertical axis until AB makes an angle of 30° with a frontal plane. Then tilt the object forward about AB as an axis until the base makes an angle of 30° with a horizontal plane.



Note: Bolt holes to be drilled later.

Figure 10-IX. Anchor Plate

# CHAPTER X

## DIMENSIONING

1-X. As outlined in Chapter V, Theory of Drawing, Article 1-V (page 50), drawings are used (1) to describe the shape of objects or structures, and (2) to specify the size of the structure as a whole, the size of its constituent parts, and the location of the parts. The size of an object is represented on a drawing by dimensions.

2-X. Lines and Symbols. The lines and symbols, Figure 1-X, used in placing dimensions on a drawing are:

1. Extension lines (witness lines), are fine, full lines, extending from the drawing to indicate the limits of the line, or the distance, to be measured when the dimension is placed outside the view. They should not quite touch the outline of the drawing and should extend a short but uniform distance past the arrow point of the dimension line.

2. Dimension lines are fine, full lines drawn parallel to the line, or the distance, to be measured. They terminate in an arrowhead.

3. Arrowheads are placed on the ends of dimension lines and leaders and are made free-hand, long, slim, and tapering. The size of the arrowhead will depend on the available space in which the head is placed. The point of the arrow should just touch the line referred to and should neither overrun nor fall short of the line.

4. Leaders are fine, full lines terminating in an arrowhead and are used to indicate a point, line, or surface to which a dimension or note refers. The shorter ones are made free hand. The longer ones are usually ruled.

5. Center lines are used when convenient as extension lines, but never as dimension lines. The distance from center line to center line should always be shown.

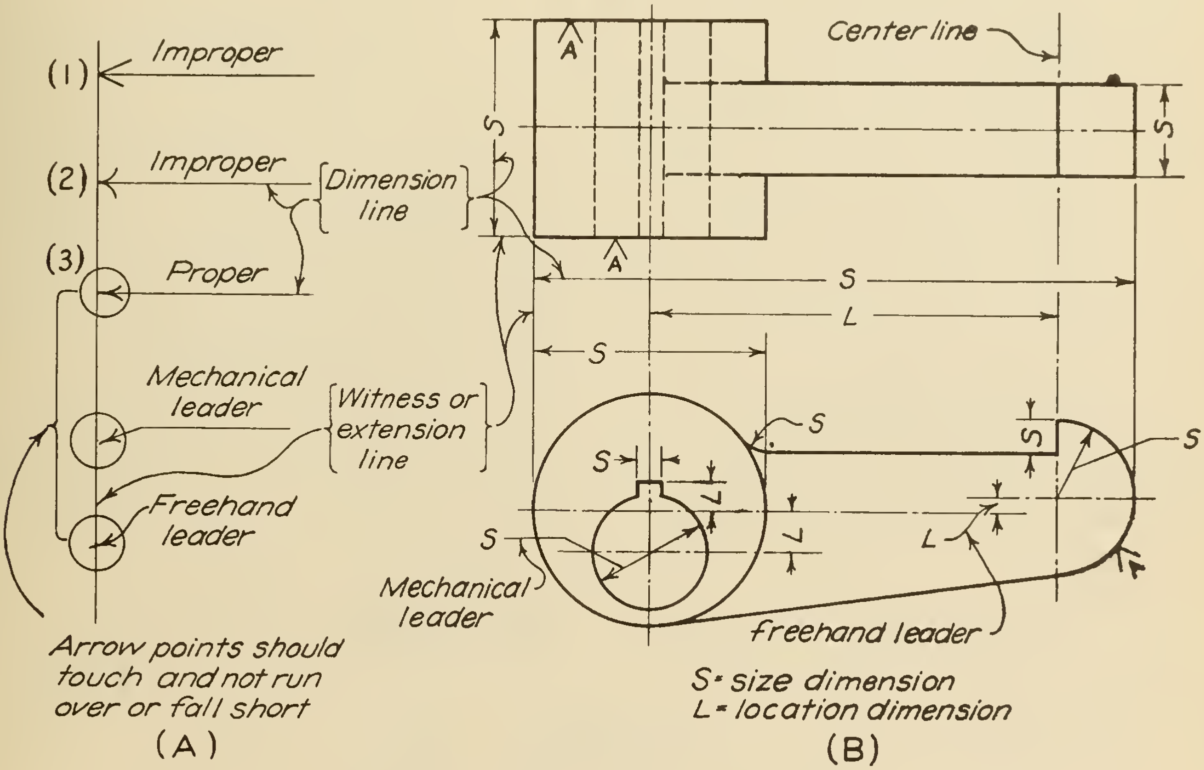


Figure 1-X. Dimension Symbols and Theory

6. Finish marks, V, are used to indicate that certain surfaces of the object are to be machined, then finished in the required manner. Allowance must therefore be made on the casting, or forging, for finish. The symbol is placed touching the line, which represents the surface to be finished, as an edge view. It is a 60° V with a code figure or letter (such as A, B, C, etc.) inserted in the opening of the V, see Figure 6-X. The code letter indicates the quality of finish desired.

7. Numerals must be carefully made in either vertical or inclined style and drawn to a size that is easily read, usually 1/8 inch, Figures 4-X, 5-X, and 6-X. The beginner is likely to get them too small and to crowd them too much. Means of relieving crowded conditions are illustrated in Figure 3-X. A space should be left around every letter, figure, or character. The finish mark, V, part 6, above, is an exception. The beginner should always draw guide lines for each numeral or letter.

Fractions should be made with a horizontal division line, drawn in line with the dimension line or leader. It should be remembered that the total height of the fraction is nearly twice as high as the numeral.

8. Feet and inches are indicated by giving the foot dimension first, inches next, as, 2'-9", 0'-6", 5'-0". When the dimensions are all given in inches, the inch marks are usually omitted, as in Figures 4-X, 5-X, and 6-X.

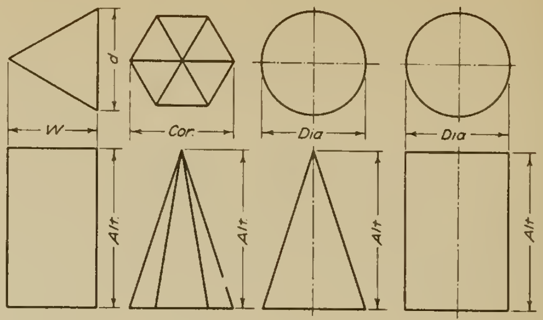


Figure 2-X. Dimensioning Elementary Geometrical Structures

3-X. Theory of Dimensioning. The position and character of the lines composing a drawing tell the shape of the object, while dimensions are used to describe the size of the structure and the location of its various parts within the structure, Figure 1-X. The function of a drawing is primarily:

1. To describe the shape of objects by line representation.
2. To specify the size of objects by giving the following dimensions:
   - (a) The size of the structure and the size of its constituent parts.
   - (b) The location within the structure of the various parts.

The most complicated structures can be analyzed into the geometrical elements (point, line, surface), and these elements in turn describe the simple geometrical shapes (prism, cylinder, cone, pyramid, and occasionally a double curved or a warped surface) which go to make up the structure.

Size dimensions for these simple structures can best be placed as shown in Figure 2-X. A dimension should be placed on the view which shows the distance dimensioned to best advantage, i.e., the dimension

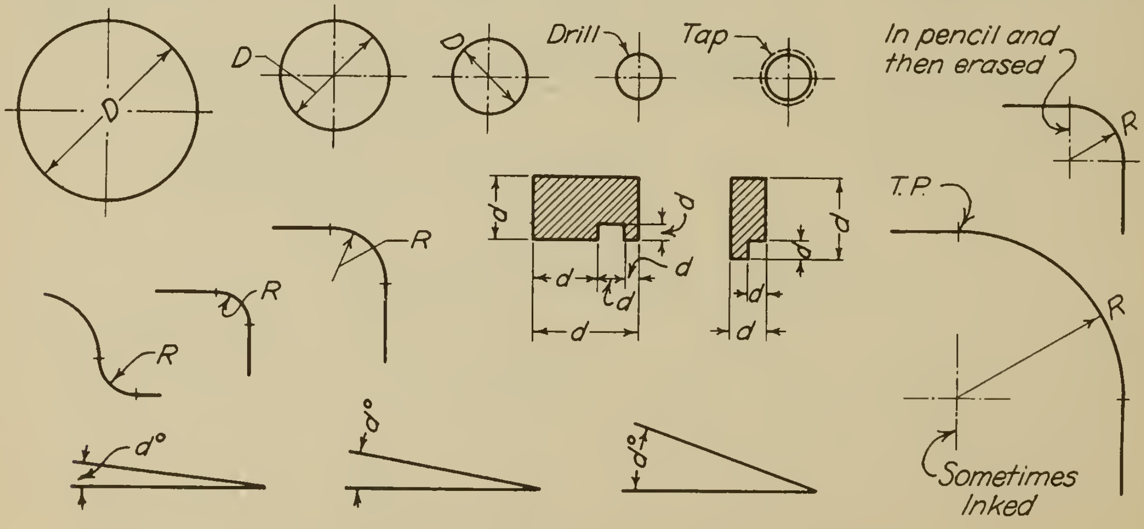


Figure 3-X. Special Features in Dimensioning

representing a diameter, a base line, an altitude, a distance across corners, etc., should be placed where these distances can actually be seen and read. Dimensions should preferably be placed between views. It may then be referred to either view. A dimension can usually be placed to good advantage on the view showing the object in configuration.

Location dimensions should be placed according to the shop practices or construction methods employed by the mechanic or technician. They are more difficult to locate than the size dimensions. The position of one part of the structure with respect to other parts should be kept in mind. It is not only necessary to give the size of the hole to be drilled, for instance, but the mechanic must know the position of the hole. It might take one or two dimensions to locate the position of a part. If the position of a piece can be located from the geometry of the structure, then a location dimension will not be necessary. The location of circular parts is usually given from center line to center line. A location dimension should not be given from a rough edge of an object, as a casting for instance. The edge should be a finished surface if so used. Center lines of the object can be used if a machined surface is not available.

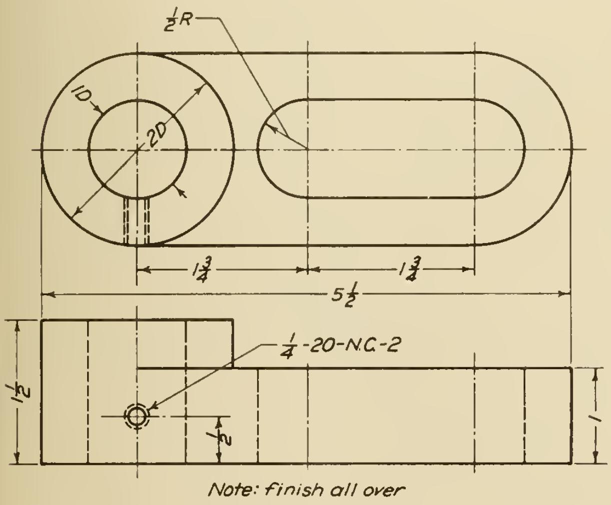


Figure 4-X. A Study in Dimensioning

4-X. Application. In order to dimension a working drawing intelligently the draftsman must know the use to which the drawing is to be put. He must understand shop terms and practices if he is to make shop drawings. Otherwise he is apt to indicate impossible operations. If making structural drawings, he should understand construction methods, for the same reason. Likewise, the map draftsman should be acquainted with surveying and mapping principles and know the use to which maps are to be put if he is to do his work intelligently. This knowledge can be gained through study, observation, and experience.

The American practice generally has been to give dimensions on machine drawings in inches divided into 1/16ths or multiples thereof, an exception being the Ford Motor Company, which gives all dimensions in decimals of an inch, as 3.410. In ordinary cases the degree of accuracy is not given. That means that a 3/8-inch bolt, for instance, will be sure to fit in a 3/8-inch drilled hole. When closer fits are desired, as in the construction of machines assembled in the shop, the practice is to mark both parts in a connection, or fit, as "running fit", "loose fit", "drive fit", "shrink fit", thus leaving the amount of allowance to machine shop practice. Dimensions for "fits" are usually given in decimals, as 2.125". With the introduction of mass production and interchangeable parts, a higher degree of accuracy became necessary. The amount of allowance, called "tolerance", is given in decimals of an inch. The steam engine piston of Figure 6-X, on the following page, is marked with a tolerance of plus or minus one-ten-thousandths. The drawing of

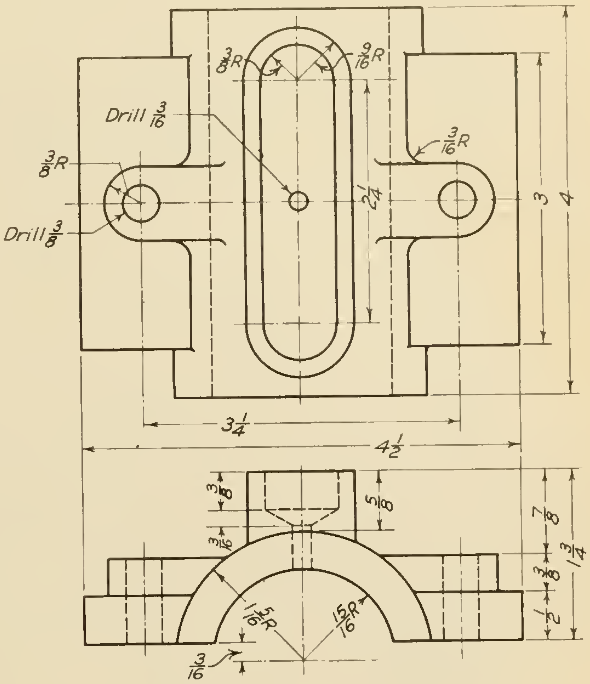


Figure 5-X. A Study in Dimensioning

the cylinder should carry the same tolerance. When the two articles are manufactured as indicated, the piston can easily be "lapped in" and the proper fit obtained.

It often becomes necessary in the production of working drawings to supplement the graphical language with notes from the spoken language. It is usually necessary to give certain specifications, indicate a definite operation, materials to be used, quantities, and the like, that can be represented only by notes. Such notes are usually lettered near the parts referred to, unless the data can be assembled in such form as a bill of material, a summation of notes, etc., and are usually placed in the lower right-hand corner of the drawing. Thread specifications and allowances, for instance, are placed near the part referred to.

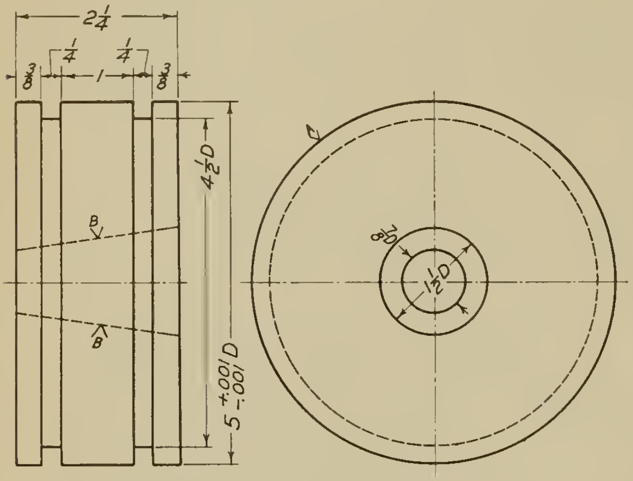


Figure 6-X. A Study in Dimensioning

5-X. Rules for Dimensioning. 1. Place dimensions so that a drawing can be read from the bottom or right side. Notes are usually placed so they can be read from the bottom.

2. Place a dimension on the view in which the distance dimensioned is most easily read and understood.

3. It is desirable to keep dimensions off the face of a drawing. In general, place them between views.

4. Do not refer dimensions to hidden outlines, unless in so doing the making of an additional view is avoided, and then only if the dimension on the dotted line can be easily read.

5. Do not repeat dimensions, except for special reasons. Do not clutter a drawing with unnecessary dimensions.

6. Keep dimension lines parallel and uniformally spaced. "Stagger" dimensions if the space is limited.

7. Give location dimensions from center lines of the object or from finished surfaces. Circular parts should have dimensions shown to their centers and not to their edges, i.e., from center to center.

8. Put the shorter dimensions next to the drawing, the longer ones farther away. The dimension lines of a string of dimensions should line up. If more than two such dimensions should fall in line, a summation (total) dimension should be given outside the shorter ones. A workman should never be required to make additions or subtractions. He should not be expected to scale a drawing.

9. Do not crowd dimensions. A fraction division line should be horizontal. Remember the fraction is taller than the numeral.

10. In general, give over-all dimensions.

11. Give the diameter of a circle, not the radius. Put "D" after a diametrical dimension, unless "drill", "tap", etc., are specified. Put "R" after a radial dimension.

12. Show a cutting plane only once, (dash-double-dot). It should be labeled (as M-M). Arrows should be drawn to indicate the direction the observer is looking when the section is seen. The sectional view should be marked (as Section M-M).

6-X. Recommendations of the American Standards Association. Certain recommendations in dimensioning and specifying finish are given in Figure 7-X on the following page. Attention is called to the "approved" and "not approved" forms of drawings (A) and (C). It should be noticed from drawing (E) that dimension lines are not broken in structural drafting. The manner of dimensioning compound and irregular curves is illustrated in drawings (F) and (h) respectively. The "finish" of a surface may be specified as shown in drawings (B), (I), and (J). In (I), the finish intended for "B", "C", "D", etc., would necessarily have to be given in a note on the specifications.

## EXERCISES

7-X. If problems are desired for this chapter, the instructor should assign objects from the Chapters on Principal Views, Auxiliary Views, or Section Drawing (preferably objects that have already been drawn) and require the student to dimension them.

The student might be required to

reproduce the objects of Figures 1-VII, 2-VII, 3-VII, 4-VII, 6-VII, etc., by scaling dimensions from the text, after a definite scale has been assigned. He should then place these dimensions on the drawing.

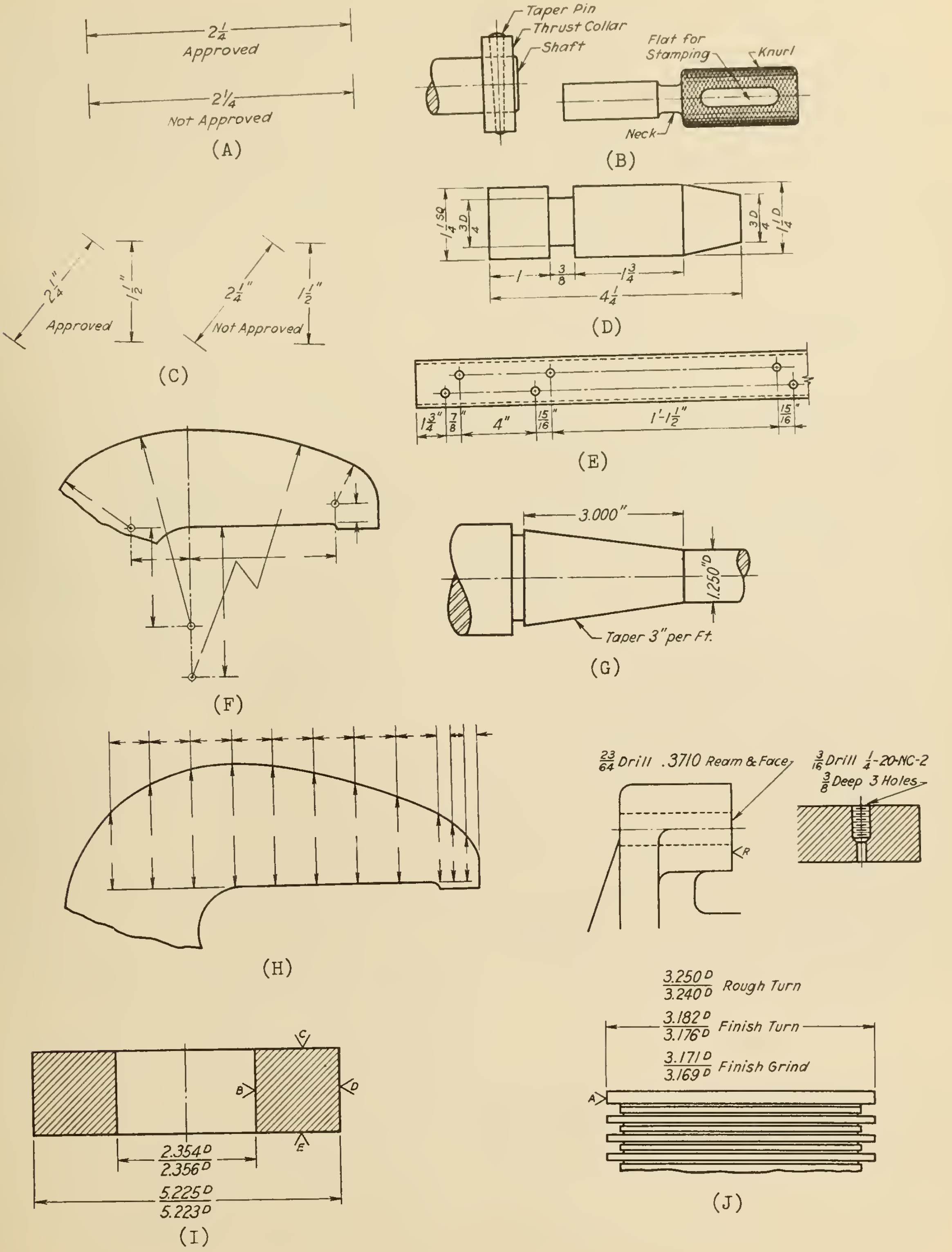


Figure 7-X. Dimensioning Recommendations of the American Standards Association

# CHAPTER XI

## POINT, LINE, AND PLANE PROBLEMS

1-XI. The elements of structure, as previously pointed out, are (1) points, (2) lines, and (3) surfaces, which are illustrated in Figure 1-IV.

The line, unless otherwise stated, is taken to be a straight line. Only plane surfaces are treated in this chapter. Curved lines (plane curves and space curves) are treated in Chapter IV and should be reviewed thoroughly.

2-XI. The Point Defined. Points on a line limit a certain portion of the line. The point therefore has no dimensions. It has position only.

3-XI. The Line Defined. A straight line is generated by a point moving in a constant direction. The intersection of two planes form a line. The line therefore has position, direction, and is indefinite in length. When a definite portion of a line is considered, then the line is said to have length. It is determined or fixed (1) by locating two points on the line (not in the same position), or (2) by fixing one point and determining the direction of the line.

4-XI. The Plane Defined. A plane is a ruled surface, i.e., generated by a straight line, so that the line joining any two points will lie wholly within the plane. A plane therefore has position, direction, and two rectangular dimensions, but no thickness. It is indefinite in extent. A definite portion of the plane can be bounded by lines. That portion of the plane, therefore, is limited in extent. The plane is determined by (1) three points not in the same line, (2) line and a point without the line, (3) intersecting lines, (4) parallel lines, (5) a point or a line and the direction of the plane.

### LINES

5-XI. True Length, Slope, and Bearing of a Line. The true length of a line was determined by the auxiliary view method, Chapter VIII and by revolution, Chapter IX. The auxiliary method will be used here, Figure 1-XI.

The slope of a line is the angle which the line makes with a horizontal plane. This angle is seen in true size only when the line is seen in true length and the horizontal plane is seen as a line (edge view). Figure 1-XI illustrates this principle. The auxiliary elevation is used and is taken perpendicular to the line AB, which is therefore seen in true length. The horizontal plane, BCD is seen as a line, and the true slope of AB is the angle indicated.

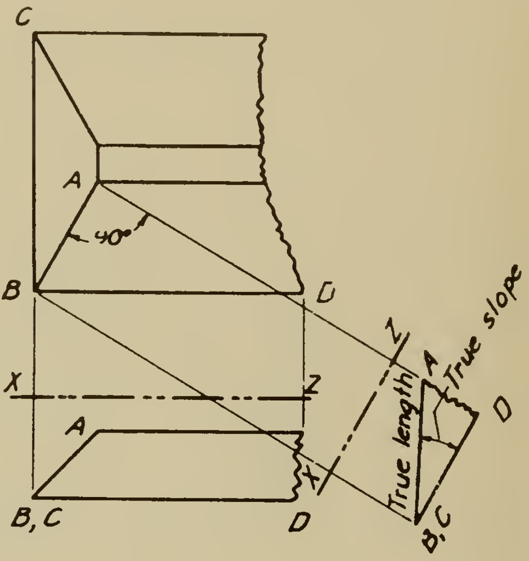


Figure 1-XI. True Length and Slope of a Line

Only an auxiliary elevation will show the true slope of an oblique line.

The different drawings of Figure 2-XI, on the following page, illustrate the various methods of designating (1) bearing, (2) slope, (3) batter, (4) pitch, and grade with several applications. These applications should be mastered. It should be noticed that the bearing of a line is a plan view and the angle, therefore, is an horizontal angle. Also, the batter of a wall and the slope of earthwork (or angle of repose of earth) are given in terms of the cotangent of the angle. The other forms of slope, pitch, and grade are given in terms of the tangent of the angle. In all cases--with the exception of the bearing of a line--the reference lines from which

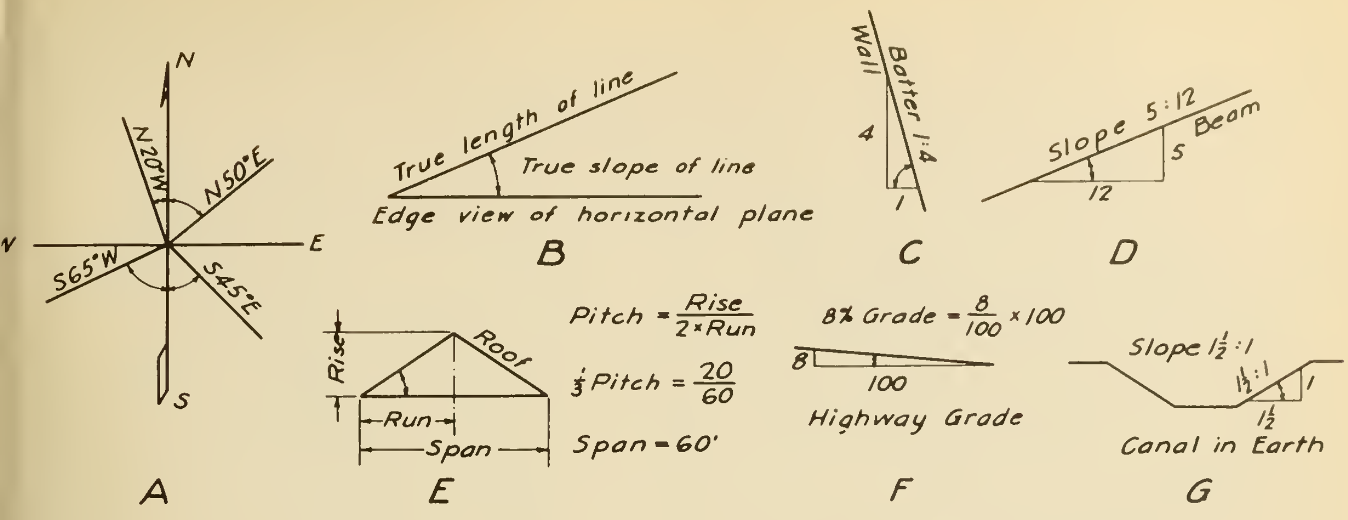


Figure 2-XI. Methods of Indicating Bearings and Slopes

the various angles are laid off are edge views of horizontal planes, as can be seen.

6-XI. Intersecting Lines. Lines in a plane intersect if they are not parallel (parallel lines intersect at infinity). Two lines can intersect at one point only. Lines AB and CD, Figure 3-XI (A), intersect at point P. Therefore, the front and top views of P both lie on a vertical ray. Lines MN and RK, part (B), do not intersect. They appear to intersect at O in the top and S in the front views. Since these two points do not lie on the same vertical ray the lines do not intersect.

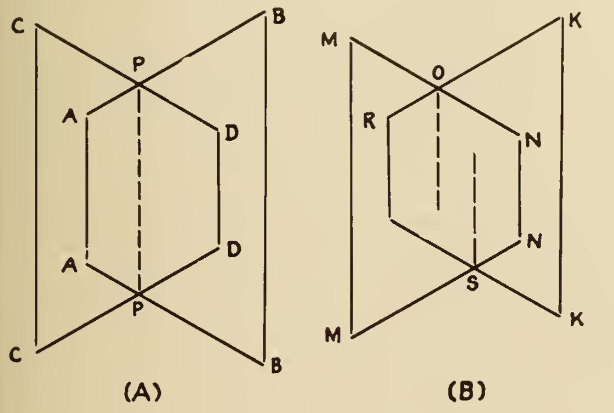


Figure 3-XI. Intersecting Lines

7-XI. Parallel Lines. If two lines are parallel in space, they are parallel in all views of these lines, Figure 4-XI (A). The converse of this statement is also true. If two lines are parallel to one of the principal planes, they will appear parallel in the other principal views that do not involve the plane to which they are parallel. To illustrate: Lines MN and RS, Figure 4-XI (B), are profile lines (parallel to a profile plane). They therefore appear parallel in the front and top views. A profile view, however, shows these lines as being nearer perpendicular than parallel.

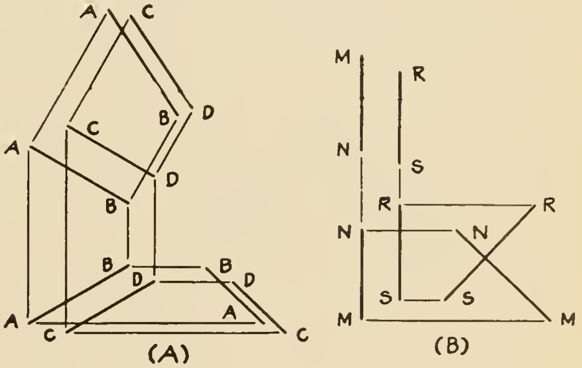


Figure 4-XI. Parallel Lines

8-XI. Perpendicular Lines. A right angle is inscribed in a semicircle. If two intersecting lines are perpendicular in space, they will appear perpendicular in any view which shows the true length of one or both of the lines. When one line shows as a point, the angle cannot be seen.

From the front view of Figure 5-XI (A) it can be seen that the right triangle ABC is a normal view in the top. Therefore, AC and BC are normal, and angle ACB is seen as a right angle. The triangle in part (B) is revolved. Side AB is held horizontal and point C is elevated. Only line AB is seen in true length in the top view, but angle ABC is checked as a right angle. With AB as an axis, and held level in the front view, point C can be revolved into any position, C', but angle ABC remains a right angle.

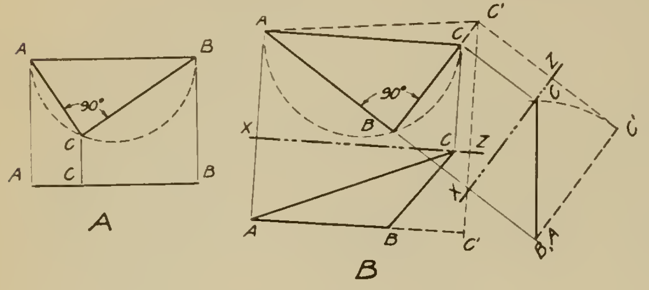


Figure 5-XI. Perpendicular Lines

9-XI. Distance from a Point to a Line. Given: Line AB and point P. Required: Line OP which is the distance (perpendicular distance) from P to AB, Figure 6-XI.

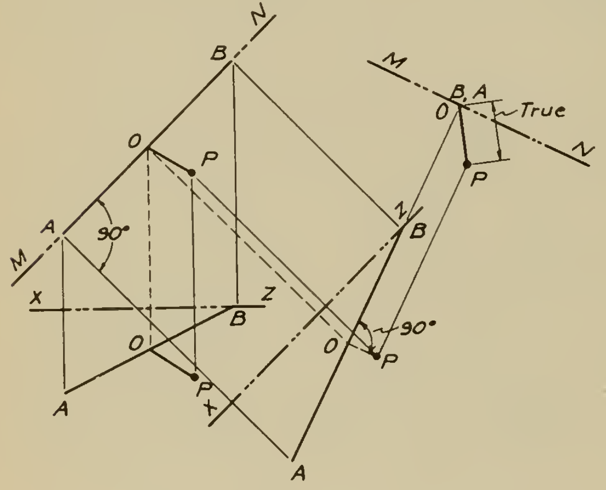


Figure 6-XI. Distance from a Point to a Line

Using an auxiliary elevation, obtain AB in true length. Show point P in this view. From P draw a line perpendicular to AB (since AB is normal) and intersecting AB at O. Line OP is the distance but it is not normal. The true length of OP is easily obtained in the auxiliary oblique--as shown. Another auxiliary could be drawn or the line could be revolved in order to obtain the true length.

10-XI. Highway Grade and Bearing. Given: Highway grade = 12%, bearing of center line of road = N 30° E. Required: Plan, true profile, and front elevation of the center line, Figure 7-XI.

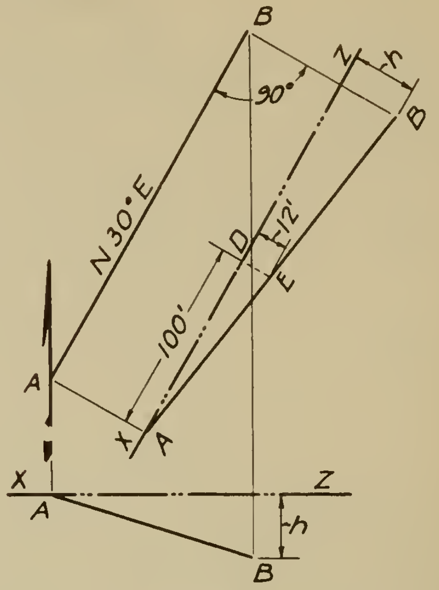


Figure 7-XI. Highway Grade and Bearing

In the plan view lay off line AB having a bearing of N 30° E. and with a chosen length. Draw visual rays from A and B at right angles to AB. Establish the reference plane X-Z and locate A on the plane. Measuring from A to the right along the horizontal plane X-Z, lay off AD = 100', using a definite scale. From D, measuring downward parallel to the auxiliary rays, lay off DE = 12'. Draw AE extended until it cuts the ray from A thus locating B. Point B is a distance h below the horizontal plane X-Z. Lay this distance off in the front elevation, thus locating B and the front elevation of AB. The auxiliary elevation shows the true length and grade of AB and is therefore the true profile. The bearing of the road is shown in the plan view. A map is a plan view. All projections on a map are horizontal measurements.

11-XI. Line Perpendicular to Two Intersecting Lines. Given: Lines AB and AC, Figure 8-XI on the following page, intersecting at A. Required: Line AP to be constructed perpendicular to AB and AC.

Obtain a normal view of AC. At A erect a perpendicular to AC and select a point P on the perpendicular at some convenient place. The elevation of P is now determined. It is a distance h from the horizontal plane X-Z. Obtain the normal view of AB. At A erect a line perpendicular to AB. Locate point

P on this perpendicular at an elevation h above the horizontal plane X-Z. From P in these two elevation views, draw rays back to the top view. The intersection of these two rays will locate P in the top. The point can now be located in the front view as indicated.

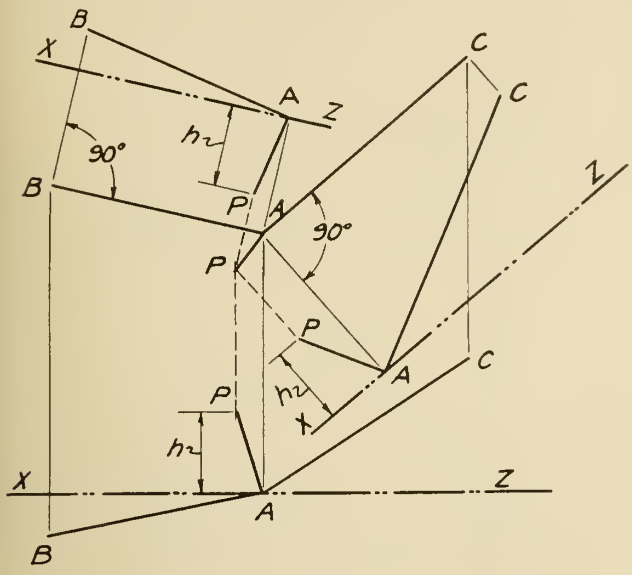


Figure 8-XI. Line Perpendicular to Two Intersecting Lines

12-XI. The Common Perpendicular to Two Non-intersecting Lines. In locating the common perpendicular to two non-intersecting lines, the observer should be in a position looking in the direction of one of the lines (DC in this case), Figure 9-XI. Such a view is obtained in the auxiliary oblique. Then the common perpendicular OP is seen in true length and is therefore erected perpendicular to AB. Given: AB and CD, the center lines of two penstocks. A cross connection of the shortest possible length is desired. Required: The common perpendicular, OP, to be shown in all views.

Obtain an auxiliary elevation of the system showing CD in true length. Next draw an auxiliary oblique looking in the direction of CD. Line CD will be a point. Through this point erect a perpendicular to AB and intersecting AB at P. Locate P on AB in the auxiliary elevation. From P in this view erect a perpendicular to CD and intersecting CD at O. (Why should OP be drawn perpendicular to CD in the auxiliary elevation?) Line OP is the common perpendicular and can now be drawn in all views.

13-XI. The Shortest Horizontal Line Connecting Two Non-Intersecting Lines. If an outside line is parallel to any line in a plane, the outside line is parallel to the plane.

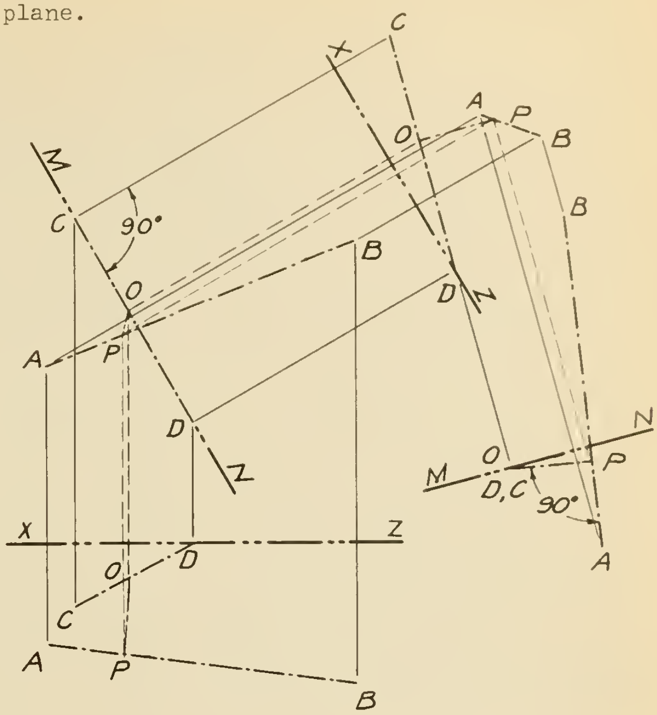


Figure 9-XI. The Common Perpendicular to Two Non-intersecting Lines

Given: The center lines of two mine tunnels, AB and CD. Required: The shortest possible connecting tunnel, OP, with a zero grade, Figure 10-XI.

Draw a plane ABM parallel to CD, i.e., AM is parallel to CD. Obtain an auxiliary

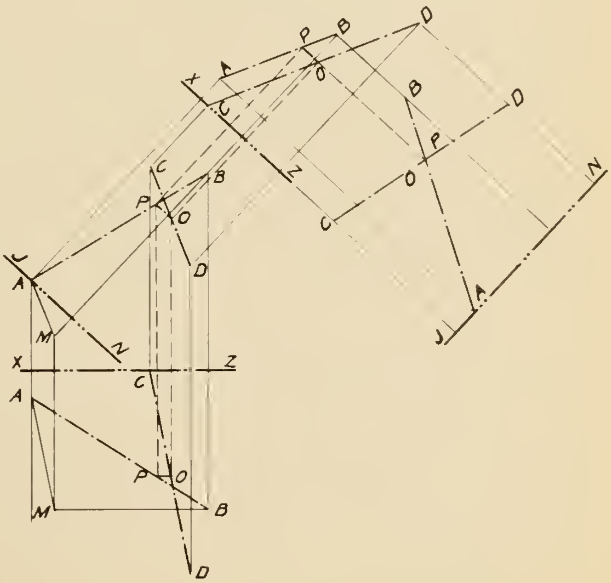


Figure 10-XI. The Shortest Horizontal Line Connecting Two Non-intersecting Lines

elevation of the system in which plane ABM is seen as an edge view. In order to obtain such a view, the direction of sight BM must be horizontal (a level line in the front view) and must lie in the plane. The edge view of the plane and the line CD appear parallel. The desired line, OP, will be perpendicular to the visual rays in the edge view, and another auxiliary elevation will have to be drawn of AB and CD in order to determine the position of OP in the edge view just completed. Draw a second auxiliary (lower right) taken in the direction of OP in the first auxiliary. The direction is horizontal (since OP is horizontal), therefore, the second auxiliary is an elevation view. The intersection of AB and CD in the second auxiliary gives the location of OP. Show this shortest level line in the other three views as indicated.

14-XI. Angle Between Two Lines. The "Perpendicular Line" problem is a special case of the problem involved here.

Any plane angle may be represented larger or smaller than itself in a system of orthographic drawings, Figure 11-XI (A).

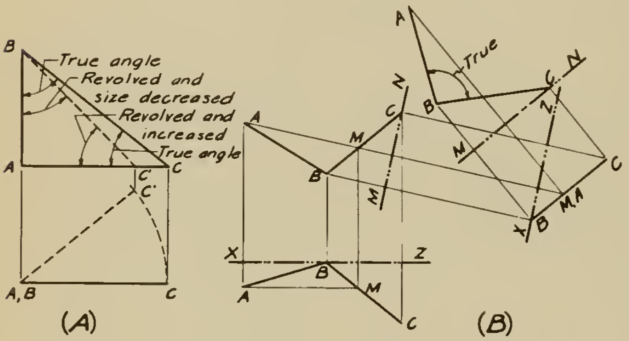


Figure 11-XI. Angle Between Two Lines

An orthographic view which shows the true angle between two oblique lines must show the true length of the two sides or the normal view of the plane determined by the two lines.

Given: Intersecting lines AB and BC. Required: True size of angle ABC.

In an auxiliary oblique, obtain a normal view of the lines AB and BC, which is a normal view of the plane ABC. First, draw the auxiliary elevation which shows plane ABC as an edge, Figure 11-XI (B). The elevation view must be taken in a horizontal direction, AM, as previously explained, in order to obtain an edge view of ABC. Draw the auxiliary oblique in a direction perpendicular to the edge view of the plane in order to obtain a normal view of ABC. The true angle is indicated in the oblique.

PLANES

15-XI. Horizontal, Frontal, and Profile Lines Drawn in a Plane. The manner of drawing horizontal, frontal, and profile lines in a plane is illustrated in Figure 12-XI and is self-explanatory. The horizontal line AM is normal in the top view and level in the front view. The frontal line CN is normal in the front view and level in the top view. Both views of the profile line OP lie in the same vertical line and can be seen in true length in a side view, or the true length can be obtained by revolution.

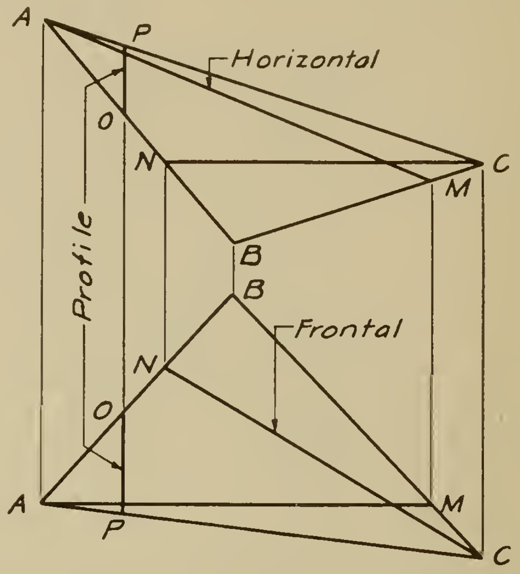


Figure 12-XI. Horizontal, Frontal, and Profile Lines Drawn in a Plane

16-XI. Edge View of a Plane. In order to obtain an edge view of an oblique plane an auxiliary must be taken in a direction of some line within the plane. If an auxiliary elevation is used, the direction of the line is horizontal. If an auxiliary right or left should be used, the direction of the line would have to be frontal. And should an auxiliary front or rear be desired, the line of sight should be taken in a profile direction.

In Figures 10-XI and 11-XI edge views of planes were obtained by taking the lines of sight parallel to a horizontal line in the planes, which resulted in auxiliary elevation views, as explained in the accompanying articles. The method of revolution is convenient for the solution of this problem.

17-XI. Normal Views of an Oblique Plane. The manner of obtaining a normal view of an oblique plane is illustrated in

Figure 11-XI and described in Article 14-XI. It has also been obtained on other occasions. The normal view of an oblique plane is readily found by the method of revolution, as previously illustrated.

18-XI. Slope of a Plane. Only one line passing through a point in a plane can have the same slope which the plane has (true slope). This line must be perpendicular to the visual rays. The slope of various lines in a plane varies from zero to a maximum value equal to the slope of the plane. Therefore, no line can have a greater slope than the slope of the plane.

The slope of a plane is the angle the plane makes with a horizontal plane, as illustrated in Figure 13-XI. It is obtained in any view which shows both the given plane and a horizontal plane as edge view. The slope may be measured in degrees or given as the tangent of the angle, with exceptions as pointed out in Article 5-XI.

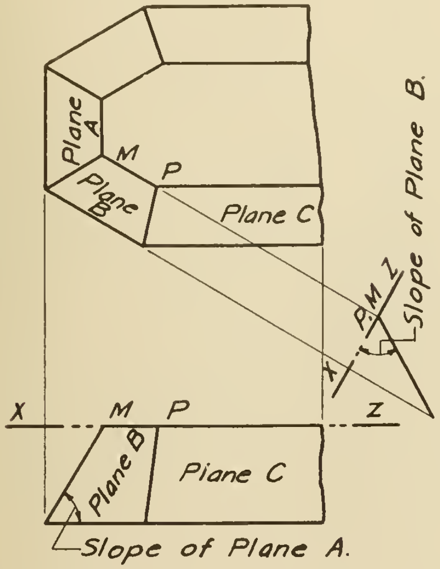


Figure 13-XI. Slope of a Plane

19-XI. Perpendicular Lines and Planes. To draw a line perpendicular to a plane, Figure 14-XI (A):

Given: Plane ABC and point O. Required: To draw a line through O perpendicular to ABC.

Draw the horizontal line AM. In the top view, draw OP perpendicular to AM. Draw a frontal line. In the front view, draw OP perpendicular to AN.

To draw a plane perpendicular to a line, Figure 14-XI (B):

Given: Line CD and point R. Required: To draw a plane through R perpendicular to CD.

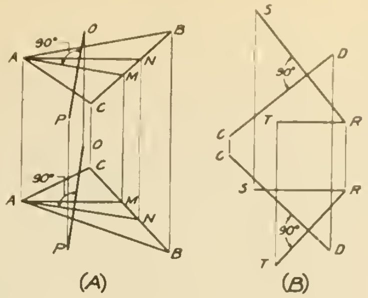


Figure 14-XI. Perpendicular Lines and Planes

Draw the horizontal line RS. In the top view RS will be perpendicular to CD. Draw the frontal line RT. In the front view RT will be perpendicular to CD.

If it were required to draw a plane perpendicular to a given plane, proceed as in Figure 14-XI (A) by drawing line OP perpendicular to ABC. Now through point O draw some line in general, say OQ. Plane OPQ will then be perpendicular to ABC.

20-XI. Piercing Point of a Line and a Plane. In the solution of piercing point and surface intersection problems, the edge view of a surface is always involved.

To find the piercing point, P, where line OM, Figure 15-XI, intersects the plane ABC which is a receding plane in the top view: Since all points in plane ABC must lie on the line ABC in the top view, piercing point, P, which is in ABC must lie on ABC in the top view. Point P must also lie on the line OM, since OM intersects the plane at P. The only place where both conditions are satisfied is where OM and ABC cross in the top view. To locate P in the front view, draw a vertical ray from P in the top intersecting OM in the front.

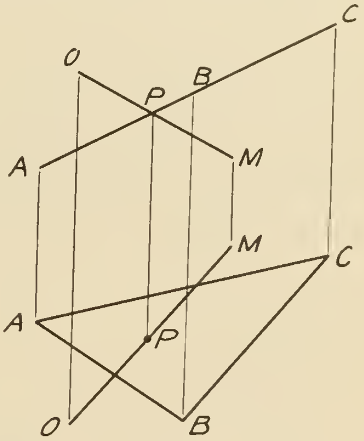


Figure 15-XI. Piercing Point of Line and Receding Plane

To determine a piercing point in general. See Figure 16-XI for pictorial illustration:

Given: Plane MNO and line CD. Required: The piercing point, P, where CD intersects MNO.

Through CD erect a vertical plane V-V. Locate point 1 where MN pierces the receding plane V-V. Determine point 2, using line NO in a like manner. Line 1-2 is the intersection between the receding plane V-V and oblique plane MNO. Point P must lie on line 1-2 since it is in both planes. Point P is also on CD. Therefore, P must lie at the intersection of CD and 1-2.

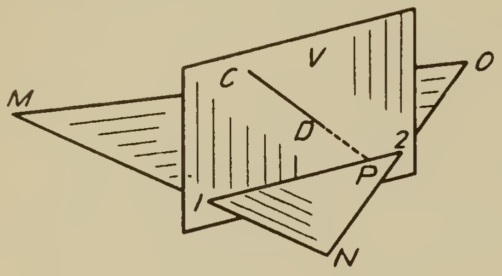


Figure 16-XI. To Determine a Piercing Point in General

Given: Oblique plane ABC, Figure 17-XI, and line MN. Required: Piercing point P.

Through MN erect a vertical plane V-V. Locate 1-2, the line of intersection between V-V and ABC, as outlined above. These points are located first in the top view. Locate 1 on AC and 2 on BC in the front view, thus determining 1-2 in the front. Produce 1-2 and M-N in the front until they intersect at the desired point, P. Point P can now be located on MN in the top view.

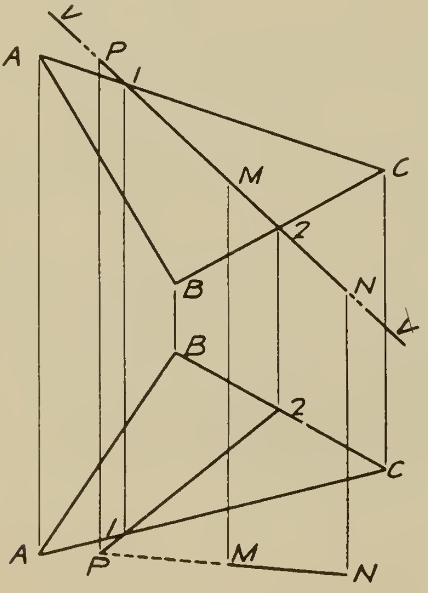


Figure 17-XI. Piercing Point of a Line and a Plane

21-XI. Distance from a Point to a Plane. The distance from a point to a plane will be the perpendicular distance.

Given: Plane ABC and point P. Required: Distance PO from point P to plane ABC, Figure 18-XI.

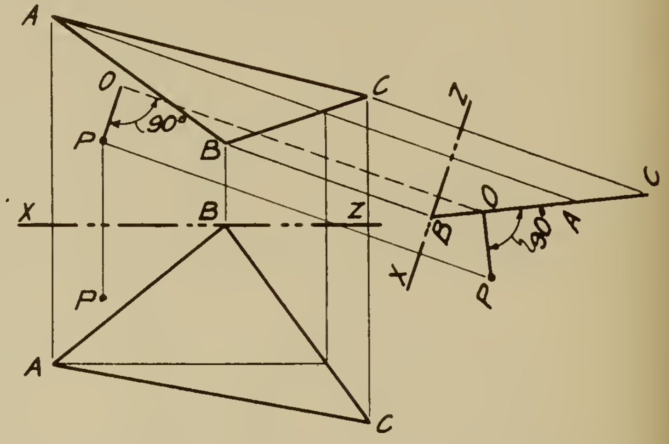


Figure 18-XI. Distance from a Point to a Plane

Obtain an auxiliary elevation of the system showing the plane as an edge. Through P in the auxiliary, erect a perpendicular to ABC which pierces the plane at O. Line PO is the desired distance and is in true length in the auxiliary.

Another method often used is: Through point P erect a perpendicular to ABC. Obtain the piercing point of this perpendicular and the plane, which is point O. Find the true length of OP by the normal view method or by revolution.

22-XI. Contour Maps. A map is a plan view of a certain area on the earth's surface. In order to indicate on the map the changes in elevation on the ground, a series of horizontal lines called contours are drawn. Such a drawing is called a contour map, Figure 19-XI. The upper part of the drawing is a map, and the lower part is a pictorial representation of the earth's surface. The contours will in general be irregular in outline since they are connecting all points on the ground at a certain elevation. The map of Figure 19-XI has a scale of 1" = 500' and a contour interval of 25'. By these intervals it is meant that horizontal planes are passed 25' apart intersecting the earth. The lines of intersection are the contours.

Railroads, highways, trails, and the like, are first projected (drawn) on the map with the specified data such as bearing (alignment), grade, etc., and the map is used in the field for the final location on the ground. Projections on a map are horizontal distances.

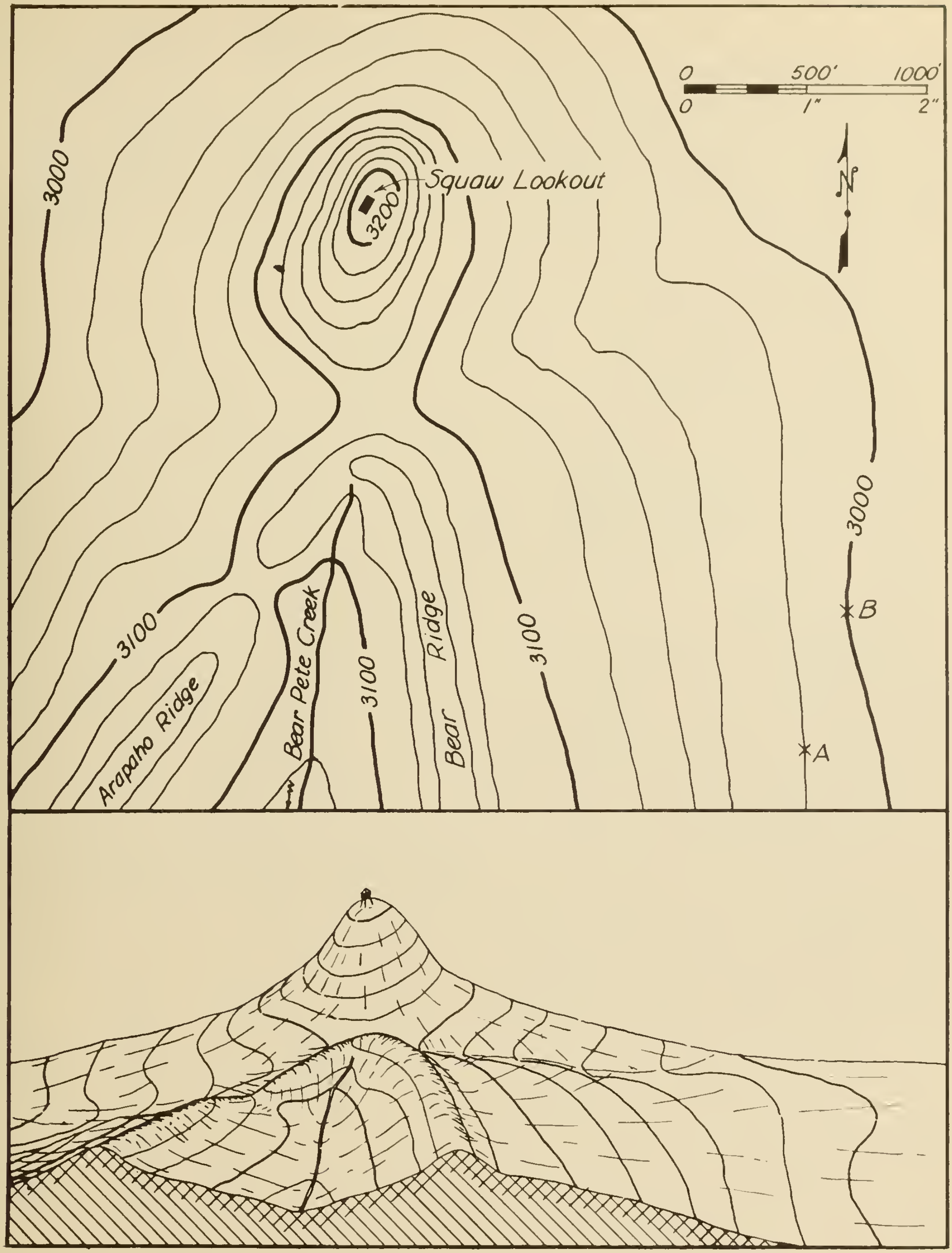


Figure 19-XI. Contour Map

It is desired to project on the map the center line of a road having a constant grade of 5% and starting at point A, which is on the 3025' contour. The next point located will be on the 3050' contour, a rise of 25' and is located by sweeping an arc with a radius of 500' and center at A cutting the 3050' contour. It might be desirable to locate some intermediate contour lines at certain localities by interpolating between the ones given.

When making a projection on curving contours, such as the ones defining Squaw Lookout, a circular arc of 500' is used, when a 5% grade is specified, and is placed so that the two ends rest on contour lines. The easiest method is by trial and error. A string is cut representing a length of 500'. It is placed on the map and adjusted, with either end on two consecutive contours, until it approximates a circular arc. A light line is sketched where the string lies. The radius and center representing the arc are determined, and the arc is drawn with a compass. The arc just drawn is rectified by laying it off on a tangent so as to check its length. This procedure is repeated until the desired length of arc is obtained.

23-XI. Intersection of Planes. The line of intersection between two planes is common to both planes. This problem is merely an extension of the problem of finding the piercing point of a line and a plane.

To determine the line of intersection between two planes: Find where two lines in the first plane pierce the second plane. These two piercing points lie on the desired line of intersection and therefore determine the line.

A solution of the problem of this article is illustrated in Figure 20-XI. In this case, the planes do not overlap in either view. A second solution (when the planes are overlapping) is given in Ch. XVII.

Given: Planes DEF and JKL. Required: The line of intersection, PO, between the two planes.

Draw V-V, a receding plane in the top view. Locate 1-2 and 3-4, the lines of intersection between the receding plane and planes DEF and JKL, respectively. The intersection of 1-2 and 3-4 locates P, a point on the desired line of intersection between the two given planes. Draw T-T, a receding plane in the front view. Locate 5-6 and 7-8, the lines of intersection between T-T and the planes DEF and JKL, respectively. The intersection of 5-6 and 7-8 determines O, a second point on the desired line. A line drawn through P and O is the required line of intersection.

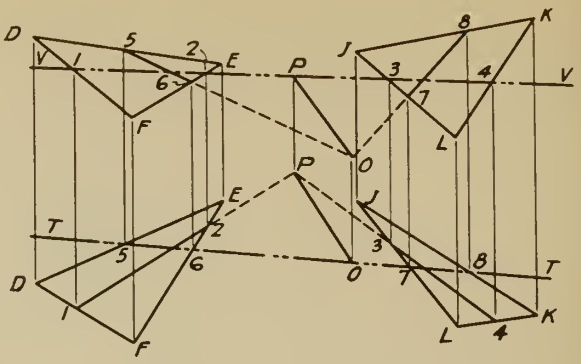


Figure 20-XI. Intersection of Planes (First Method)

24-XI. Strike and Dip of a Vein. Geological maps, in addition to surface contour lines, show boundaries of various rock formations, lines in which various ore bodies intersect the surface of the ground (called outcrops), and locate these stratified rocks or veins by giving the strike and dip of the vein. Ore bodies are usually very thin and are considered as a plane. The plane is determined on the map by locating a horizontal line in the vein and by giving the direction of the vein (angle the vein makes with a horizontal plane). If the thickness of the vein is to be considered, then a working plane is taken in the vein halfway between the upper and lower faces of the vein.

Strike is the direction of any horizontal line in the vein, Figure 21-XI. The elevation of the strike is usually given. Strike AB occurs on the 400' elevation, while MN is taken on the 500' elevation. These elevations are shown in the front view.

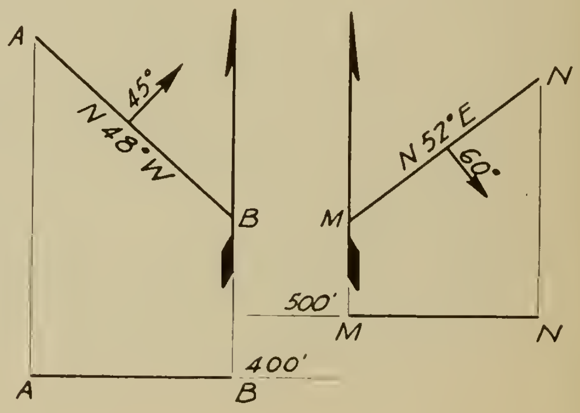


Figure 21-XI. Strike and Dip of a Vein

Dip is the angle the vein makes with a horizontal plane, Figure 21-XI. It is obvious that the plane might dip in either of two directions, i.e., northward or southward, eastward or westward. Therefore the arrow indicates the direction of dip. The amount of dip in degrees is written along the arrow.

25-XI. Intersection of Two Veins. An enrichment of metal can be expected at the intersection of two ore veins. In Figure 22-XI, the ore veins of Figure 21-XI are reproduced, and the intersection of the two veins is determined.

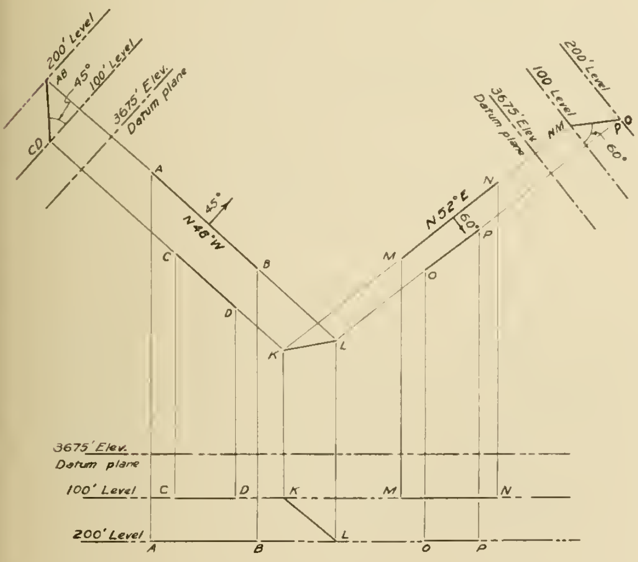


Figure 22-XI. Intersection of Two Veins

Given: Strikes AB and MN with dip of each vein as shown in Figure 22-XI. Required: Line of intersection, KL, of the two veins.

Obtain an edge view of the vein looking in the direction of the horizontal line MN, which is on the 100' level. Locate OP, the strike on the 200' level. Show both lines in the front elevation. The various levels are referred to the 3675' elevation as a datum plane. Obtain an edge view of the other vein looking in the direction of AB, which is on the 200' level. Obtain in this view line CD, the strike on the 100' level. It should be noticed that these veins are dipping below the horizontal at the specified angles and in the directions indicated by the arrows. Lines AB and OP are on the 200' level. Since they are not parallel they must therefore intersect. Their point of intersection, L, is a point on the desired line of intersection between the two given veins. Likewise, CD and MN are on the 100' level. Their point of intersection, K, is a second point on the desired line. A line drawn through K and L is the line of intersection between the two ore veins.

26-XI. Angle Between a Line and an Oblique Plane. The angle between a line and a plane is seen in true size when the line is shown in true length and the plane is shown as an edge view, as illustrated in Figure 23-XI, the indirect method. The direct method of Ch. XVII (page 204) will be found useful at times.

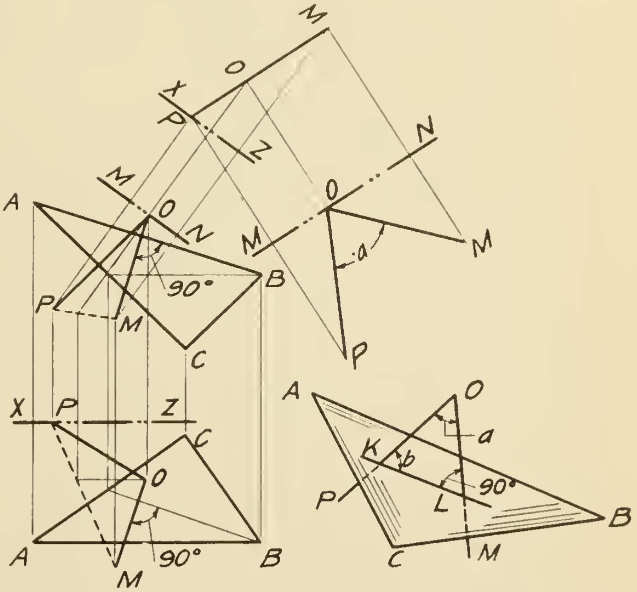


Figure 23-XI. Angle Between a Line and an Oblique Plane (Indirect Method)

Given: Plane ABC, Figure 23-XI, and line OP. Required: The angle between the plane and the line. Principles involved: Erect a plane MOP perpendicular to ABC and including OP. The intersection of the two planes is some line KL (see pictorial). The angle, b, between OP and KL is the desired angle. If a third line is considered, OM, which was drawn perpendicular to the plane, a right angle triangle will be formed. Angle MOP, which is easily determined, is therefore the complement of the desired angle.

Procedure for indirect method: Draw line OP perpendicular to plane ABC. Obtain by the normal view method the true size, a, of the angle MOP. The desired angle b = 90-a.

27-XI. Angle Between Two Oblique Planes. A plane drawn perpendicular to two given intersecting planes will be perpendicular to the line of intersection of the given planes.

The angle between two planes is usually referred to as the dihedral angle.

Procedure for direct method: In Figure 24-XI, it is desired to find the angle between the various faces of the hopper. Faces ABCD and BCEF are chosen. The line of intersection is BC.

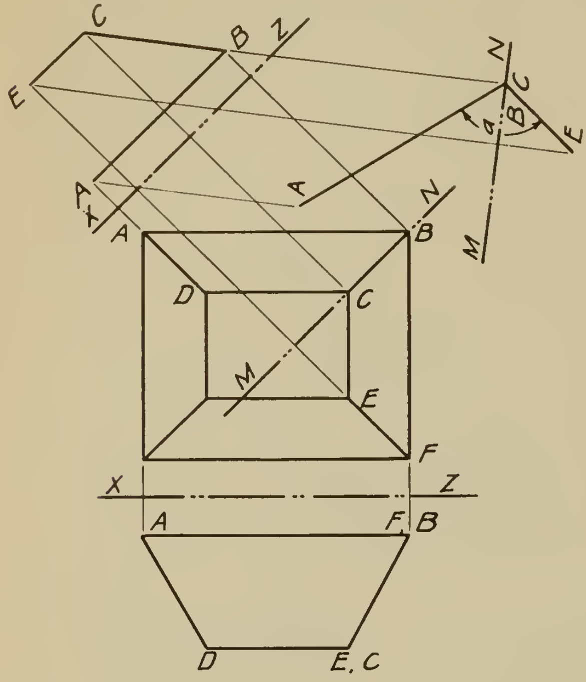


Figure 24-XI. Angle Between Two Oblique Planes (Direct Method)

Given: Planes ABC and EBC. Required: dihedral angle by the direct method.

Obtain an auxiliary elevation of the two planes taken at right angles to BC. Obtain an auxiliary oblique of the planes taken in a direction BC. The planes will then be an edge view and BC will be a point. The required angle, a, will be seen in true size. The indirect method of Ch. XVII (page 204) will be found useful at times.

28-XI. Planes Intersecting at a Point. The three lines of intersection of three mutually intersecting planes will meet at a point. Example: Any rectangular structure, three faces of a cube, for instance, have a mutual corner, say P, in common. The three lines of intersection of the three faces all intersect at P. The dihedral angle does not necessarily have to be 90 degrees.

EXERCISES

29-XI. A space 8" x 10" will be sufficient for the following exercises, with the exceptions indicated. Many of the exercises are laid out on a rectangular coordinate system. The dimensions to be used in laying out the coordinate squares will be specified in the individual exercise.

The invert of a pipe is the inside bottom. It should be laid on an established grade line. Dimension all drawings.

Group 1-XI. True Length, Slope, and Bearing of a Line

In each exercise indicate the true length of line in feet and inches (1' - 3 1/2"), slope in terms of the tangent (5 : 12), and bearing in degrees reckoned from the north (N 38° E). Coordinate squares = 3/8".

1. Scale 1 1/2" = 1". Figure 25-XI (A) and (B).
2. Scale 1 1/2" = 1". Figure 25-XI (C) and (D).

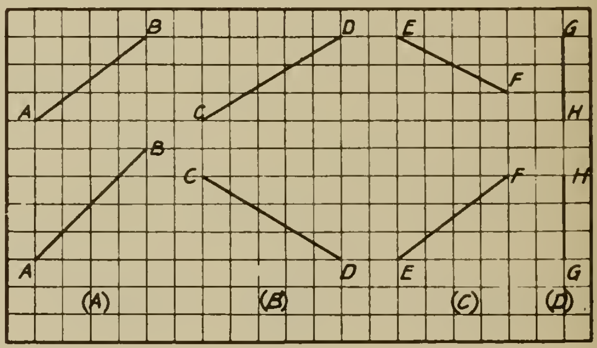


Figure 25-XI. Exercises in Point, Line, and Plane

3. Scale 1 1/2" = 1'-0". Figure 26-XI (A). Lines AE and GC.
4. Scale 1 1/2" = 1'-0". Figure 26-XI (A). Lines BF and DH.
5. Scale 1 1/2" = 1'-0". Figure 26-XI (B). Lines AC and BC.
6. Scale 1 1/2" = 1'-0". Figure 27-XI. Lines CD and AB.

Group 2-XI. Parallel Lines

In each exercise draw a line parallel to the given line and through the given point; coordinate squares = 3/8".

1. Scale 1 1/2" = 1". Figure 27-XI (A) and (C).

2. Scale 1 1/2" = 1". Figure 27-XI (B) and (D).

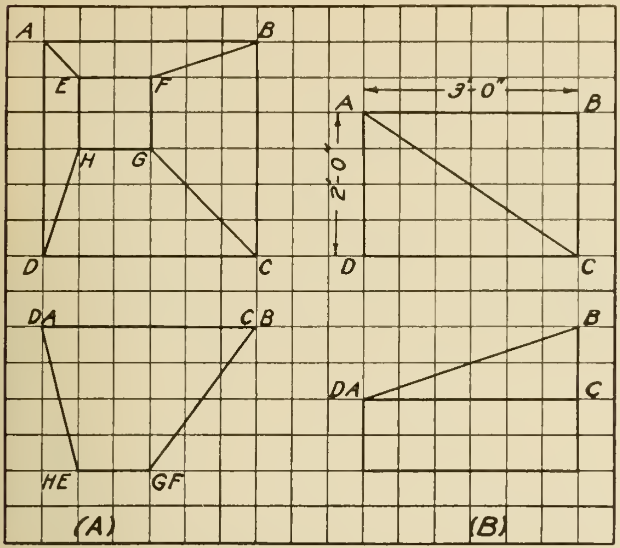


Figure 26-XI. Exercises in Point, Line, and Plane

Draw only the given point and line, omitting the rest of the drawing. Other instructions same as above.

3. Scale 1 1/2" = 1'-0". Figure 26-XI (A), point G, line DH; and point E, line FB.

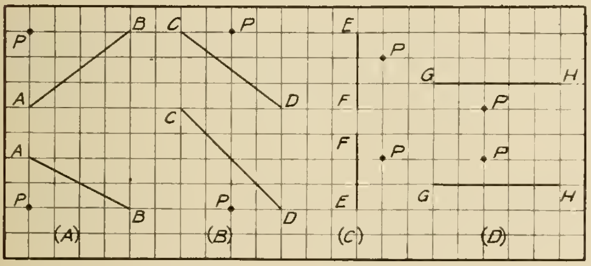


Figure 27-XI. Exercises in Point, Line, and Plane

4. Scale 1 1/2" = 1'-0". Figure 26-XI (A), point F, line AE; and point H, line GC.
5. Scale 1 1/2" = 1'-0". Figure 26-XI (B), point B, line DC; and point B, line AC.
6. Scale 1 1/2" = 1'-0". Figure 26-XI (B), point D, line AC; and point A, line BC.

### Group 3-XI. Perpendicular Lines

In each exercise draw a line perpendicular to the given line and through the given point. Check your results by a different method. Coordinate squares = 3/8".

1. Scale 1 1/2" = 1". Figure 27-XI (A).
2. Scale 1 1/2" = 1". Figure 27-XI (B)
3. Scale 1 1/2" = 1". Figure 27-XI (C)
4. Scale 1 1/2" = 1". Figure 27-XI (D).

Draw only the given point and line, omitting the rest of the drawing. Other instructions same as above.

5. Scale 1 1/2" = 1'-0". Figure 26-XI (A), point B, line GC.
6. Scale 1 1/2" = 1'-0". Figure 26-XI (B), point B, line AC.

### Group 4-XI. Distance from a Point to a Line

In each exercise obtain a true length view of the perpendicular distance from a given point to a given line. Show a dimension for this distance. Check your results by a different method. Coordinate squares = 3/8".

1. Scale 1 1/2" = 1". Figure 27-XI (A).
2. Scale 1 1/2" = 1". Figure 27-XI (B).
3. Scale 1 1/2" = 1". Figure 27-XI (C).
4. Scale 1 1/2" = 1". Figure 27-XI (D).

Draw only the given point and line, omitting the rest of the drawing. Other instructions same as above.

5. Scale 1 1/2" = 1'-0". Figure 26-XI (B), point B, line AC.
6. Scale 1 1/2" = 1'-0". Figure 26-XI (A), point C, line HD.

### Group 5-XI. Highway Grade and Bearing

In each exercise locate point A in the center and near the left border of the problem space. Locate the center line of a highway passing through A with the bearing and grade given below. Show 150' of the road in plan, profile, and front elevation. A rising grade is a plus grade; a falling grade is a negative grade.

1. Scale 1" = 50'. Center line AB, N 32 1/2$^{\circ}$ E, +12%.
2. Scale 1" = 50'. Center line AP, N 15$^{\circ}$ W, -8%.
3. Scale 1" = 50'. Center line AM, due North, +100%.
4. Scale 1" = 50'. Center line AK, N 78$^{\circ}$ E, -15%.
5. Scale 1" = 60'. Reproduce the contour map --see Article 22-XI (page 100)--and center line of a highway starting from point A, Figure 28-XI on the following page. Locate A as directed above. Draw a true view profile of each piece of tangent

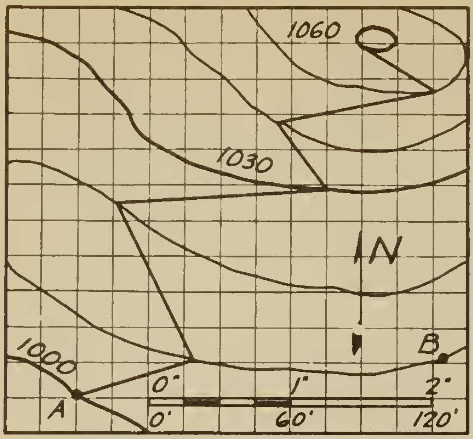


Figure 28-XI. Highway Grade and Bearing

line. Letter the bearing, length, and per cent grade on each tangent.

6. Scale 1" = 60'. Reproduce the contour map --see Article 22-XI--of Figure 28-XI. From point B draw the center line of a highway with a constant bearing of N 28 1/2° W. Letter the per cent grade and the length on each piece of tangent highway between the various contour intervals. Draw the true profile.

### Group 6-XI. Line Perpendicular to Two Intersecting Lines

In each exercise erect a perpendicular to the two given lines at their point of intersection. Draw the common perpendicular 1/2" long. Coordinate squares = 3/8".

1. Scale 1 1/2" = 1". Figure 29-XI (A).
2. Scale 1 1/2" = 1". Figure 29-XI (B).
3. Scale 1 1/2" = 1". Figure 29-XI (C).
4. Scale 1 1/2" = 1". Figure 30-XI (A), point B.

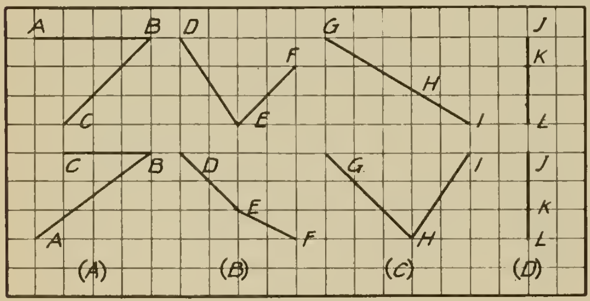


Figure 29-XI. Exercises in Point, Line, and Plane

5. Scale 1 1/2" = 1". Figure 30-XI,(B), point E.
6. Scale 1 1/2" = 1". Figure 30-XI (D), point J.

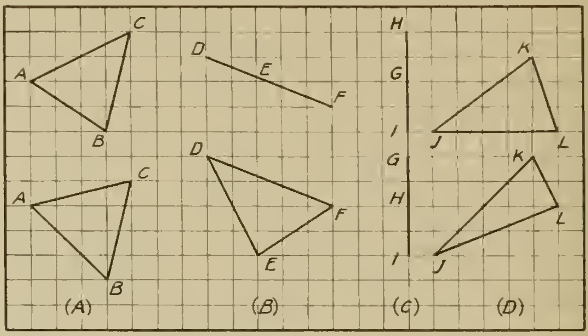


Figure 30-XI. Exercises in Point, Line, and Plane

### Group 7-XI. Common Perpendicular to Two Non-intersecting Lines

In each exercise erect the common perpendicular to the two given non-intersecting, oblique lines. Give the length in inches of the common perpendicular. Coordinate squares = 1/4".

1. Scale 1" = 1". Figure 31-XI (A).
2. Scale 1" = 1". Figure 31-XI (B).
3. Scale 1" = 1". Figure 31-XI (C).
4. Scale 1" = 1". Figure 31-XI (D).

5. Scale 1" = 60'. Locate point A near the center of the problem space. Point C is on the same level with A but is 140 feet east and 75 feet north of A.

   From A, a mining tunnel bears N 15° E and has a negative 25% (downward) grade. From C, another tunnel bears N 30° W and has a negative grade of 15%.

   It is desired to connect these two tunnels with the shortest possible tunnel. Determine: (1) Length in feet of the connecting tunnel, (2) bearing of the connecting tunnel, and (3) grade of the connecting tunnel.
6. Scale 1" = 20'. Locate A near the center of the problem space. Point B is 45 feet east, 25 feet south, and 28 feet above A. Point C is 35 feet east, 5 feet south, and 25 feet below A. Point D is 30 feet due south, and 7.5 feet above A.

   A low-pressure pipe line has the direction AB. This water main leads to a residential district. Another pipe line, direction CD, is a high-pressure main which leads to the business district. In

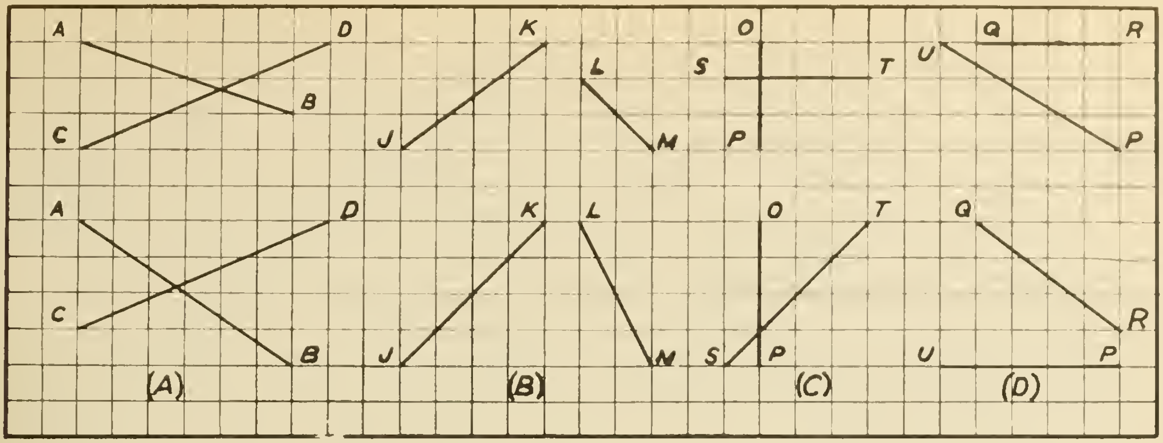


Figure 31-XI. Non-intersecting Lines

case of fire in the residential district, a cross connection is desired between the two mains. Locate the shortest possible connecting pipe and determine: (1) length, (2) slope, and (3) bearing of the connecting pipe.

### Group 8-XI. Shortest Horizontal Line Connecting Two Non-intersecting Lines

In each exercise locate the shortest horizontal line connecting the two given non-intersecting lines. Give the length in inches of the connecting line. Coordinate squares = 1/4".

1. Scale 1" = 1". Figure 31-XI (A).
2. Scale 1" = 1". Figure 31-XI (B).
3. Scale 1" = 1". Figure 31-XI (C).
4. Scale 1" = 1". Figure 31-XI (D).

5. Scale 1" = 1 mile. Locate point A just to the left of the center of the problem space. Point B is 1 1/2 miles south, 1 mile east, and 1 1/4 miles above A. Point C is 2 miles south, 1 mile east, and 2 1/4 miles above A. Point D is 1/4 mile north, 1/2 mile east, and 1 mile above A.

   Lines AB and CD are the directions of two mining tunnels. It is desired to connect them with the shortest possible level tunnel, MN. Find: (1) length, (2) grade, and (3) bearing of MN.
6. Scale 1" = 1 mile. Locate point A just to the left of the center of the problem space. Point B is 2 miles east, 1 1/2 miles south, and 2 miles below A. Point C is 1 mile east, 2 1/4 miles south, and 1 1/2 miles below A. Point D is 1 3/4 miles east, 1/4 mile south, and 1/2 mile below A.

   Lines AB and CD are the directions of two mining tunnels. It is desired to connect them with the shortest possible level tunnel, MN. Find: (1) length, (2) grade, and (3) bearing of MN.

### Group 9-XI. Angle Between Two Lines

In each exercise find the true angle in degrees between the given lines. Coordinate squares = 1/4".

1. Scale 1" = 1". Figure 29-XI (A).
2. Scale 1" = 1". Figure 29-XI (B).
3. Scale 1" = 1". Figure 29-XI (C).
4. Scale 1" = 1". Figure 29-XI (D).
5. Scale 1" = 1'-0". Figure 26-XI (A). Lines BF and BC.
6. Scale 1" = 1'-0". Figure 26-XI (B). Lines AB and BC.

### Group 10-XI. Edge View of a Plane

In each exercise obtain an edge view of the given plane. Coordinate squares = 1/4".

1. Scale 1" = 1". Figure 30-XI (A).
2. Scale 1" = 1". Figure 30-XI (D)
3. Scale 1" = 1". Figure 29-XI (A)
4. Scale 1" = 1". Figure 29-XI (B)
5. Scale 1" = 1'-0". Figure 26-XI (A). Plane DCGH.
6. Scale 1" = 1'-0". Figure 26-XI (B). Plane ABC.

### Group 11-XI. Normal View of an Oblique Plane

In each exercise obtain a normal (true) view of the given oblique plane. Give the length of each side in inches. Coordinate squares = 1/4".

1. Scale 1" = 1". Figure 30-XI (A).
2. Scale 1" = 1". Figure 30-XI (D).
3. Scale 1" = 1". Figure 29-XI (A).
4. Scale 1" = 1". Figure 29-XI (B).
5. Scale 1" = 1'-0". Figure 26-XI (A). Plane DCGH.
6. Scale 1" = 1'-0". Figure 26-XI (B). Plane ABC.

### Group 12-XI. Slope of a Plane

In each exercise obtain the slope of the given plane. Express the slope in terms of the tangent of the angle. Coordinate squares = 1/4".

1. Scale 1" = 1". Figure 30-XI (A).
2. Scale 1" = 1". Figure 30-XI (B).
3. Scale 1" = 1". Figure 29-XI (C).
4. Scale 1" = 1". Figure 29-XI (D).
5. Scale 1" = 1'-0". Figure 26-XI (A). Plane DCGH.
6. Scale 1" = 1'-0". Figure 26-XI (B). Plane ABC.

### Group 13-XI. Line Perpendicular to a Plane

In each exercise assume a point (unless one is given) in a convenient location. Erect a line containing the point and perpendicular to the given plane. Coordinate squares = 1/4".

1. Scale 1" = 1". Figure 30-XI (A).
2. Scale 1" = 1". Figure 30-XI (D).
3. Scale 1" = 1". Figure 29-XI (A).
4. Scale 1" = 1". Figure 29-XI (B).
5. Scale 1" = 3'-0". Reproduce the drawing of Figure 19-VIII (page 82). Locate the center of plane ABCD where an I-bolt is to be set in the concrete. A guy wire, making an angle of 90° with ABCD, is to be fastened to the I-bolt. Show the wire in both views of the drawing.
6. Scale 1" = 1'-0". Reproduce the drawing of Figure 20-VIII (page 82). The design of the bin calls for a 4" x 4" brace resting on the plane ABC at the center point and making an angle of 90° with ABC. Show this brace in the drawing.

### Group 14-XI. Plane Perpendicular to a Line

In each exercise assume a point (unless one is given) in a convenient location. Erect a plane containing the point and perpendicular to the given line. Coordinate squares = 3/8".

1. Scale 1" = 1". Figure 27-XI (A).
2. Scale 1" = 1". Figure 27-XI (B).
3. Scale 1" = 1". Figure 25-XI (A).
4. Scale 1" = 1". Figure 25-XI (C).
5. Scale 1" = 1'-0". Line AB is the near edge of a 12" x 12" timber beam. Point B is 2 feet east, 1 1/2 feet south, and 2 feet below A. The beam is to be cut off at points A and B by a plane which is perpendicular to the faces forming the edge of AB. The cutting planes will therefore be perpendicular to AB at these points. Make a drawing of the beam and show the two planes.
6. Scale 1/4" = 1'-0". Coordinate squares = 1/2". Figure 32-XI shows two steps of a helical stair. They are composed of vertical and horizontal planes wound around a cylinder (to the right) and are intercepted by a cylindrical handrail (right). A vertical, built-up, box column supports the stair. A vertical face of the column is perpendicular to surfaces 1-2-3-4 and 3-4-5-6 and is therefore perpendicular to their edge or line of intersection, 3-4. Point P lies in this vertical surface and is 3' below 3-4-5-6, 6' back of 1-2-3-4 and 2' to the left of point 4. Through P erect a plane perpendicular to 3-4 which will represent the vertical face of the column referred to.

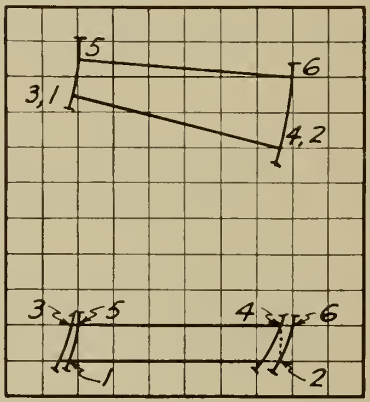


**Figure 32-XI. Helical Stair**

### Group 15-XI. Piercing Point of a Line and a Plane

In each exercise locate the point where the given line pierces the given plane. Check by an independent method.

1. Scale 1" = 1". Coordinate squares = 1/2". Figure 33-XI (A).
2. Scale 1" = 1". Coordinate squares = 1/2". Figure 33-XI (B).

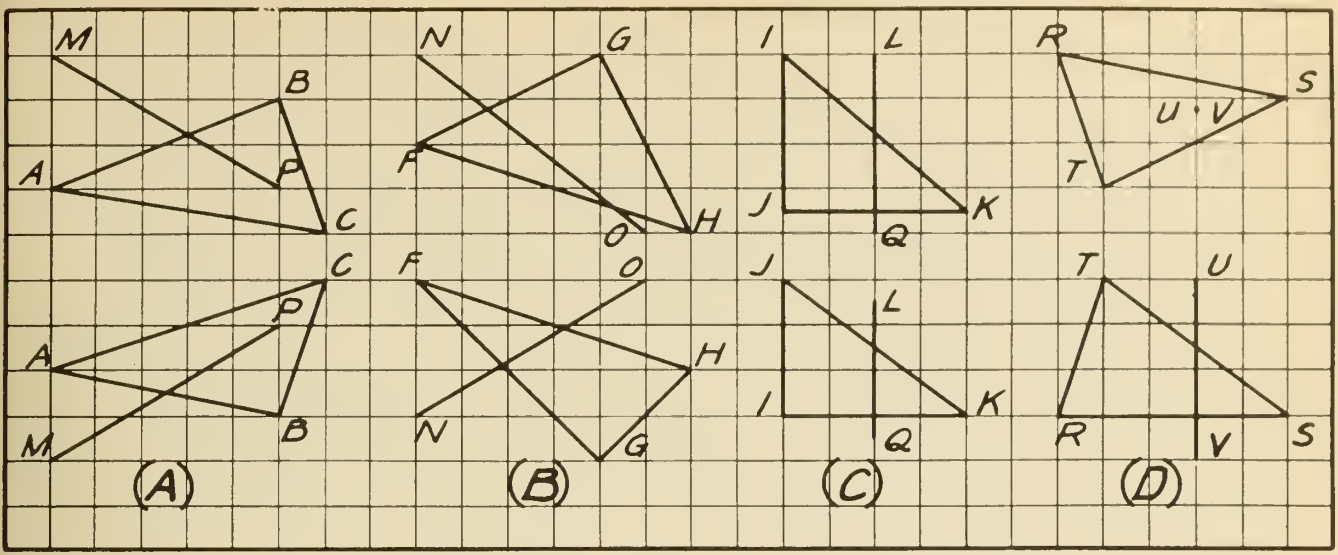


Figure 33-XI. Line and Plane Exercises

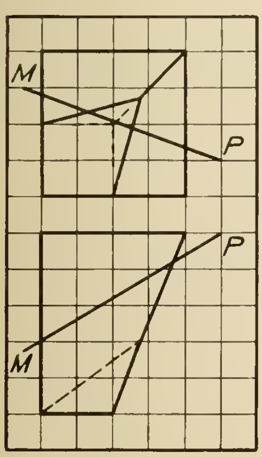


Figure 34-XI. Tipple

3. Scale 1" = 1". Coordinate squares = 1/2". Figure 33-XI (C).
4. Scale 1" = 1". Coordinate squares = 1/2". Figure 33-XI (D).

5. Scale 1/2" = 1'-0". Coordinate squares = 1/2". Figure 34-XI illustrates a tipple hopper which tips about axis MP. What faces of the hopper does MP intersect? Locate the piercing points.
6. Scale 1" = 60'. Use a double space. Copy the contour map of Figure 35-XI in the center horizontally of the double space and with the lower line of the map on the horizontal center line of the space. To simplify the solution, the contour lines should be drawn as straight lines, with a bearing of N 46° E, taken from the point where the road cuts the contour lines. The contour lines represent the ridges and valleys. The intermediate ground should be taken as a plane surface. From A the center line of a road bears S 55° E and has a constant negative grade of 11%. The construction will include a fill and a tunnel.

Required: (1) Plan view and elevation looking north, (2) Points where the center line of the road would enter and come out of the hillsides, i.e., ends of the tunnel. Use a check. (3) Draw an edge view of the ground surfaces and a profile of the road. (4) What is the length of tunnel in feet? What is the length of fill in feet? What is the greatest depth of fill?

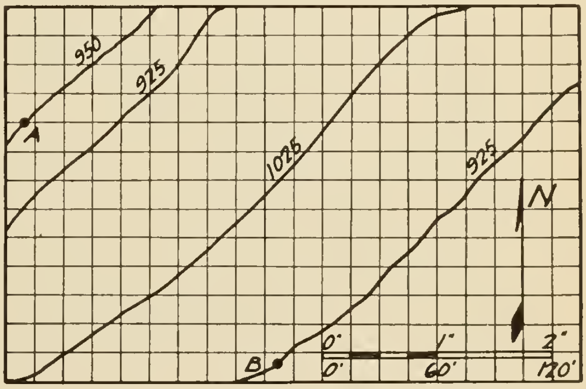


Figure 35-XI. Contour Map

## Group 16-XI. Distance from a Point to a Plane

In each exercise give the distance in inches from the given point to the given plane. Coordinate squares = 1/2".

1. Scale 1/4" = 1". Figure 36-XI (A).
2. Scale 1/4" = 1". Figure 36-XI (B).
3. Scale 1/4" = 1". Figure 36-XI (C).
4. Scale 1/4" = 1". Figure 36-XI (D).

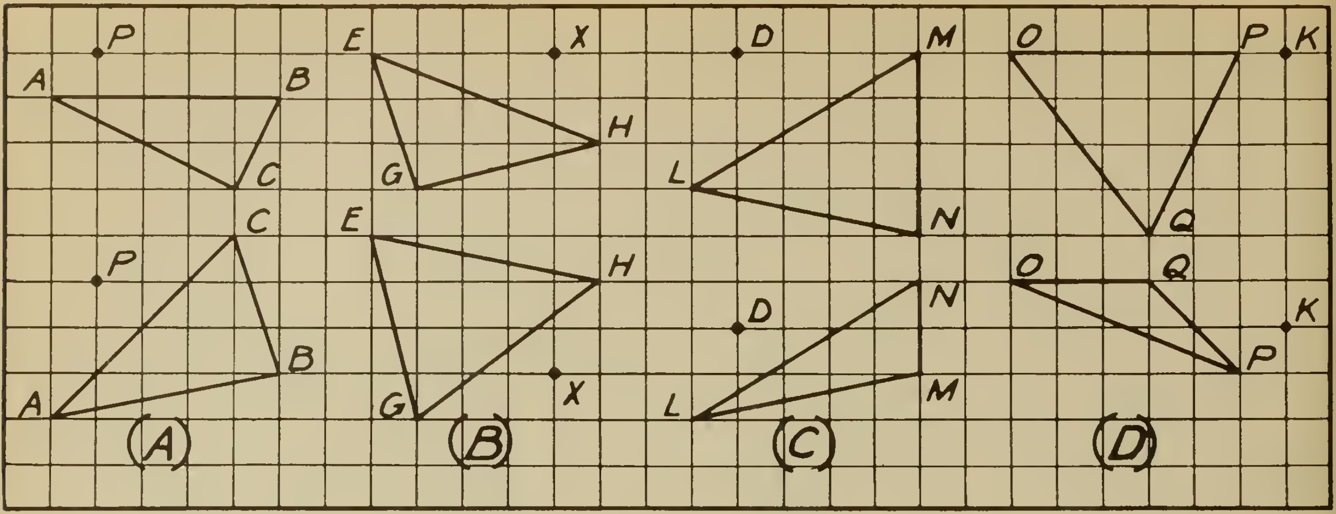


Figure 36-XI. Point and Plane Exercises

5. Scale 1" = 0.10 mile. Two points, A and B, on the outcrop of a vein of ore were discovered in the face of an eroded cliff. Point B is 500 feet above A. Point B is 0.25 mile east of A measured on the level. A third point C was located in the vein by drilling. Point C is 165 feet below, 0.125 mile north, and 0.25 mile east of A. It is desired to construct a tunnel starting at T and going directly to the vein. Point T is 0.37 mile east, 0.12 mile above, and 0.06 mile south of A. Determine: (1) length of the tunnel and (2) center line of the tunnel in all views.

### Group 17-XI. Use of Contour Maps

1. In addition to Exercise 5, Group 5, Ch. XI, (page 105), do the following: (1) From point B locate a trail to the summit with a maximum grade of 18%. (2) Locate a trail from A to the center of the 1060 contour with a constant bearing. (3) What is the bearing? (4) What is the maximum grade?
2. In addition to Exercise 6, Group 15, Chp. XI, do the following: (1) From point A locate a highway connecting point B with a maximum grade of 20%. (2) If necessary construct a fill or a tunnel, or both. If constructed, give the length of each and height of fill.
3. Scale 1" = 500'. Use a double space. Reproduce the map of Figure 19-XI. From point A locate a railroad with a constant bearing of N 68° W and a grade of +2%. (1) Locate each end of the tunnels. (2) Give the length of tunnels. (3) Give the length of fill. (4) What is the greatest depth of fill over the creek? (5) Starting at point B, locate a trail to the top of Squaw Lookout. Maximum grade 12%. (6) What is length of trail?
4. Scale 1" = 200'. Use a double space. Reproduce the map of Figure 37-XI on the following page. Construct a road from M to N. Width = 20'. Side slopes = 1 1/2 : 1. (1) Draw the contours of the cut or of the fill. (2) What is the number of cubic yards of excavation? (3) What is the number of cubic yards in the fill? (4) What is the bearing of the road? (5) What is the grade of the road?

### Group 18-XI. Intersection of Planes

In each exercise determine the line of intersection between the two given planes by locating two points on the required line and then check by locating a third point using a different method. Coordinate squares = 1/2".

1. Scale 1" = 1". Figure 38-XI (A).
2. Scale 1" = 1". Figure 38-XI (B)
3. Scale 1" = 1". Figure 38-XI (C).
4. Scale 1" = 1". Figure 38-XI (D).

5. Scale 1/8" = 1'-0". A double space will be necessary. Figure 39-XI, on page 112, illustrates the crossing of a drain and highway by means of a culvert and fill. The side slopes of the highway are 1 1/2 : 1, while the side slopes of the drain are 1 1/4 : 1. The intersections of these

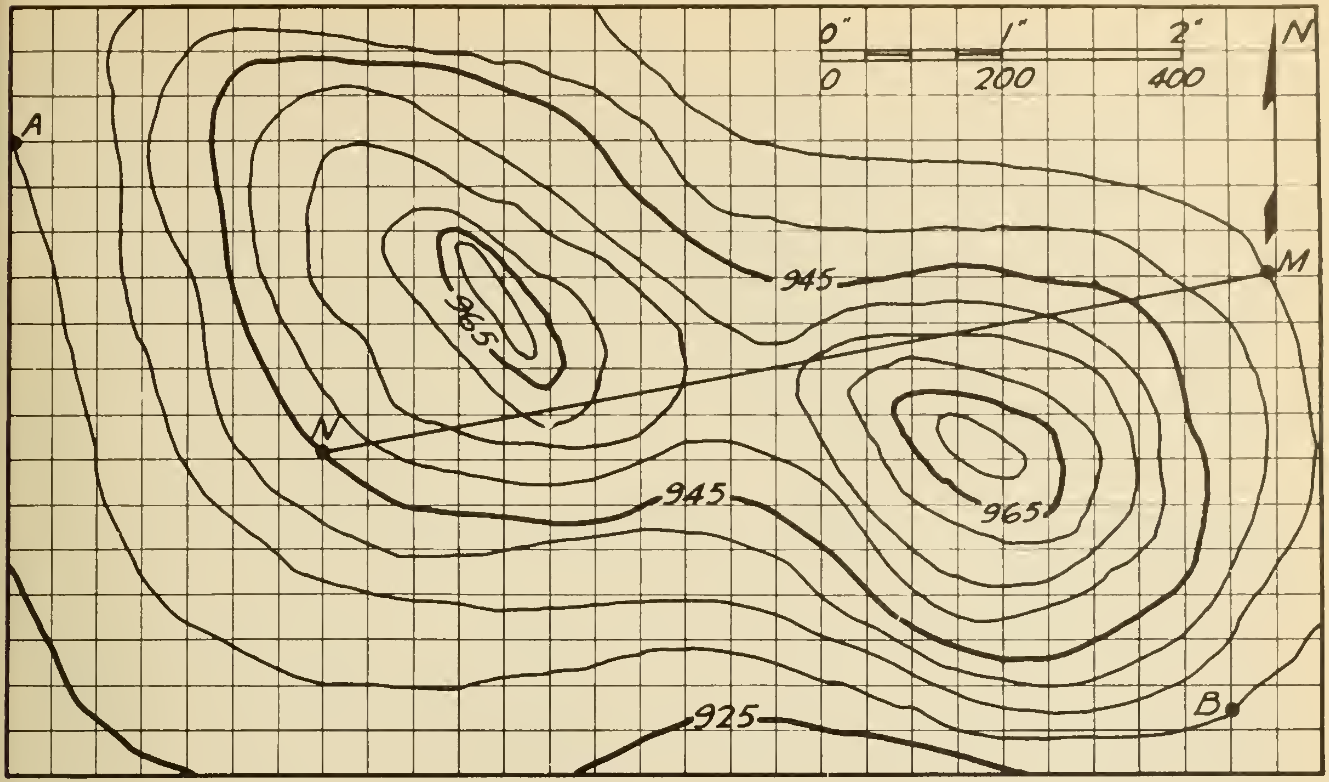


Figure 37-XI. Contour Map

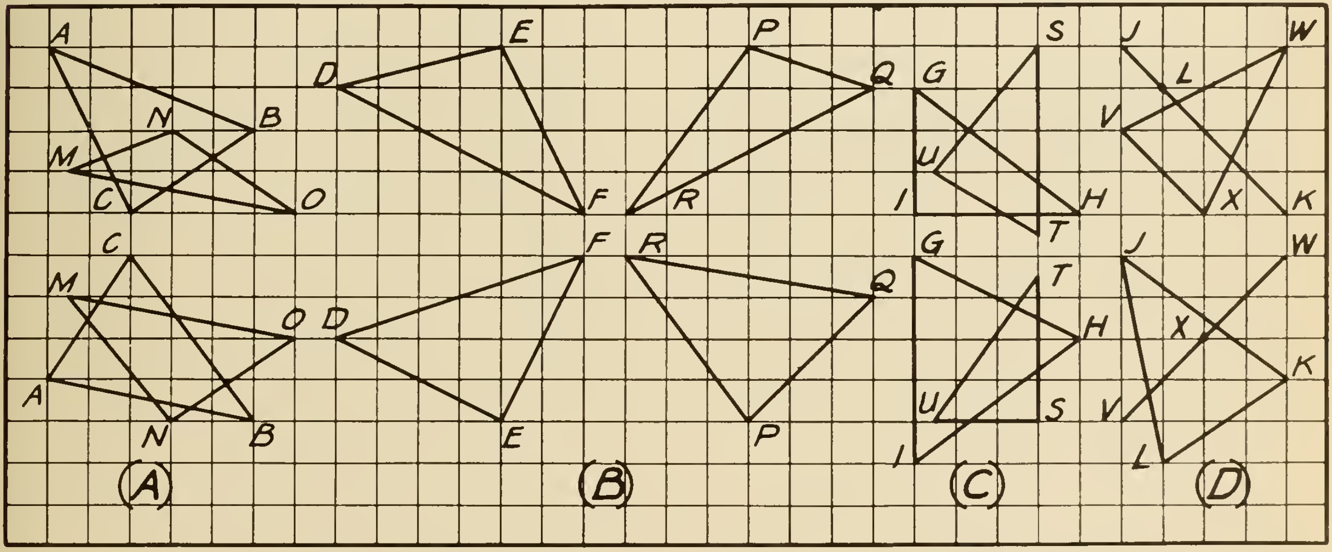


Figure 38-XI. Exercises in Planes

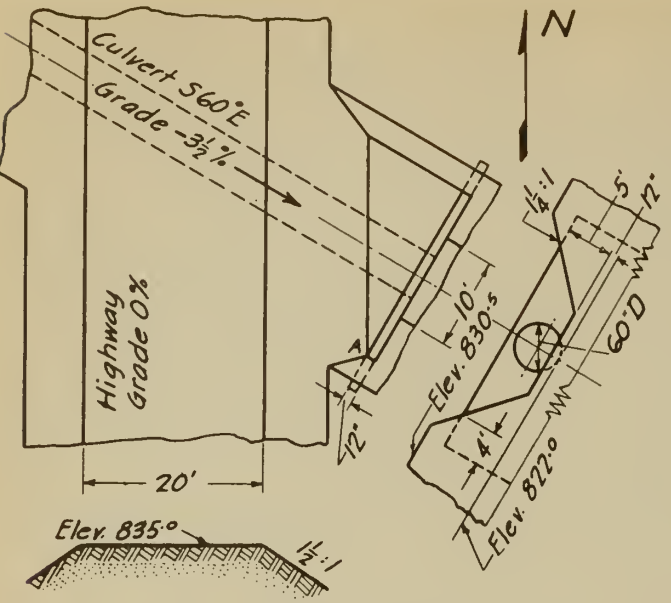


Figure 39-XI. Highway-Drainage Crossing

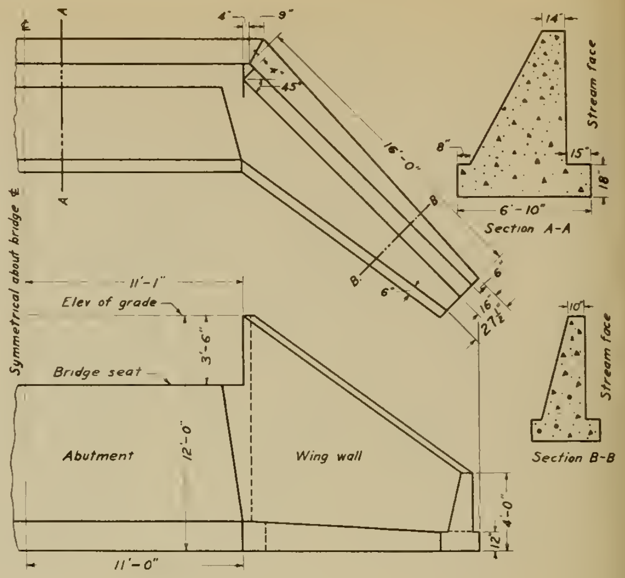


Figure 40-XI. Gravity Abutment for Beam Bridge

slopes with each other and with the horizontal surface of the fill at the ends of the culvert are straight lines. The ground surface slopes in the direction of the drain on a grade of 3 1/2%. Two of these lines meet at A which lies on the upper, inside edge of the culvert head wall. Find: (1) The lines of intersection described above. (2) The length of span of the culvert.

6. Scale 1/4" = 1'-0". A gravity abutment for a beam bridge is shown in Figure 40-XI. The reinforcing steel and some of the details are omitted. Reproduce the plan and front elevation (omit sectional views). Find: (1) The line of intersection between the inclined face of the abutment and the inclined face of the wing wall. (2) The lines of intersection between the inclined face of the wing wall and the bridge seat (a horizontal surface). Show coordinates for the lines just determined. Only a part of one line of these last two intersecting surfaces is shown.

Group 19-XI. Ore Vein Exercises

1. Scale 1" = 30'. Locate A, a point of outcrop, in the center and near the top of the problem space. Point B is 110 feet (horizontal distance) from A. The bearing of AB is S 30° W and B is 75 feet below A. At B a vertical bore hole is drilled, and ore is struck at a depth of 14 feet. Another bore hole is made at C. Point C is on the same level with B, east of A and B, 85 feet from A, and 65 feet (horizontal radii) from B. Ore is struck 40 feet below C. (1) Determine the strike and dip of the vein.
2. Scale 1" = 100'. Points M, N, and O lie on a canyon wall which dips 20° eastward. M is a point of outcrop of a vein of ore. Line MN bears S 45° E and N is 200 feet (horizontal distance) from M. Line MO bears S 15° E and O is 300 feet (horizontal distance) from M. Vertical drill holes at N and O strike ore at 75 feet and 50 feet respectively. (1) Determine the strike and dip of the vein.
3. Scale 1" = 5'. Locate A in the center of the problem space and to the left. A pioneer tunnel starting at A bears N 30° E, with a negative grade of 300%. The tunnel strikes a vein whose strike is due north, and the cut through the vein is 12 feet long. The true thickness of the vein is 7 feet. The dip is eastward. (1) What is the angle of dip of the vein?
4. Scale 1" = 3'. A vein of ore has a strike of N 60° E and dips 45° to the northwest. A pioneer tunnel cuts a core from the vein 5 feet long. The tunnel bears S 75° W and has a negative grade of 8 1/4%. (1) What is the true thickness of the vein?

5. Scale 1" = 100'. Locate point A below the center of the problem space and to the left. Point B is 300 feet east, 100 feet north of A, and on the same level with A. Point C is 400 feet east, 200 feet north, and 100 feet below A. Point D is 600 feet east, 200 feet south, and 100 feet below A.

Line AB is the strike in a vein of ore which dips northwestward 45°. Line CD is a strike in another vein which dips 60° to the northeastward. (1) Find the line of intersection between the two veins.

6. Scale 1" = 100'. Locate point M below the center of the problem space and to the left. Point N is 200 feet east, 100 feet north of M, and on the same level with M. Point O is 400 feet directly north and 200 feet above M. Point P is 300 feet east, 200 feet north, and 200 feet above M. Line MN is a strike in a vein of ore which dips southeastward 45°. Line OP is a strike in another vein which dips 60° southwestward. (1) Find the line of intersection between the two veins.
7. Scale 1" = 100'. Locate point Q below the center and to the left of the problem space. Point R is 100 feet east, and 300 feet north of Q, and on the same level with Q. Point S is 100 feet east, 100 feet north, and 300 feet above Q. Point T is 300 feet east, 100 feet north, and 300 feet above Q. Line QR is a strike in an ore vein which dips 67° northwestward. Line ST is a strike in another vein which dips 60° southward. (1) Find the line of intersection between the two veins.

## Group 20-XI. Angle between a Line and a Plane

In each exercise find the true angle in degrees between the given line and oblique plane. Coordinate squares = 1/2".

1. Scale 1" = 1". Figure 33-XI (A).
2. Scale 1" = 1". Figure 33-XI (B).
3. Scale 1" = 1". Figure 33-XI (C).
4. Scale 1" = 1". Figure 33-XI (D).

5. Scale 1/4" = 1'-0". An I-bolt has been set in the concrete flush with the inclined face of the wing wall of Figure 40-XI. The bolt is 13'-0" from the left end of the wall and 3'-9" above the bottom of the base--measured in the inclined face. The approach to the bridge is on a curve. A cable guard rail is on the east side. To take care of the tangential pull, a cable is run from the guard rail to the I-bolt in the wing wall. The cable (guy wire) has a bearing of S 40° W and a slope of 6 1/2 : 12. (1) Give angle in degrees which the guy wire makes with the inclined face of the wing wall.
6. Scale 1/8" = 1'-0". See Figure 39-XI. A temporary telephone line is run along the east bank of the highway to the intersection of the drain and then turns up the south bank of the drain. The line is supported at the turn by a guy wire which is anchored to a "dead man" in sloping surface of the north bank of the drain just below the crossing. The guy wire has a bearing of N 15° E and a slope of 4 3/4 : 12. The line is 20'-0" from the center line of the road and 10'-0" from the center line of the drain. (1) Give the angle in degrees which the guy wire makes with the north bank of the drain. Check by revolution.

## Group 21-XI. Angle between Two Oblique Planes

In each of the following exercises find the angle in degrees between the two given planes. Coordinate squares = 1/2".

1. Scale 1" = 1". Figure 38-XI (A).
2. Scale 1" = 1". Figure 38-XI (B).
3. Scale 1" = 1". Figure 38-XI (C).
4. Scale 1" = 1". Figure 38-XI (D).

5. Scale 1/4" = 1'-0". See Figure 40-XI. (1) Give the angle in degrees between the inclined faces of the abutment and the wing wall.
6. Scale 1/4" = 1'-0". See Figure 40-XI. (1) Give the angle in degrees between the concrete surface at the end of the bridge seat (which lies in a profile plane) and the inclined surface of the wing wall.
7. Scale 1/8" = 1'-0". See Figure 45-XI, Retaining Wall Construction. (1) Give the angle in degrees between the side slope of the highway and the inclined face of south wing wall.

## Group 22-XI. Planes Intersecting at a Point

1. Scale 1" = 1". Locate point A in the middle of the problem space and to the extreme left. Point B is 2" to the east, 3" north, and 3" below A. Point C is 4" to the east, 1" south, and 2" below A. Point D is 3" due east and 1" below A. Point E is 6" to the east, 1" south, and 1" below A. Point F is 7" east, 3" north, and 2" below A. Point G is 4" east, 1" north, and 1" below A. Point H is 5" east, 3" north, and 4" below A. Point J is 8" due east and on the same level with A. (1) Locate point P which lies in the three planes ABC, DEF, and GHJ.
2. Scale 1" = 1". Locate point A in the center of the problem space and well to the

left. Point B is 4" east, 3" north, and 3" below A. Point C is 7" east, 1" south, and 4" below A. Point D is 1" west, 2" north, and 3" below A. Point E is 3" east, 1" south, and 1" below A. Point F is 8" east, 3" north, and 4" below A. Point G is 1" east, 3" north, and on the same level with A. Point H is 2" due east and 3" below A. Point L is 6" east, 2" north, and 1" below A. (1) Locate point P which lies in the three planes ABC, DEF, and GHL.

3. Scale 1" = 1". Locate point A in the center of the problem space and to the extreme left. Point B is 1" east, 4" north, and 2" below A. Point C is 8" east, 1" north, and 1" above A. Point D is 2" east, 3" north, and 2" below A. Point E is 3" due east and 1" above A. Point F is 6" east, 4" north, and 1" below A. Point G is 4" east, 4" north, and 1" above A. Point H is 5" due east and 2" below A. Point M is 7" east, 1" north, and 2" above A. (1) Locate point P which lies in the three planes ABC, DEF, and GHM.
4. Scale 1" = 200'. The mine survey of Figure 41-XI shows the Texas, Dixie, and Kentucky lodes. Determine: (1) Intersection, P, of the three lodes. (2) The location and depth of a shaft (vertical) to reach P.

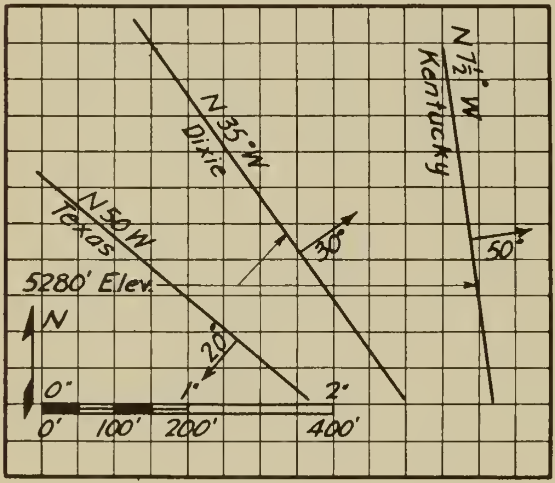


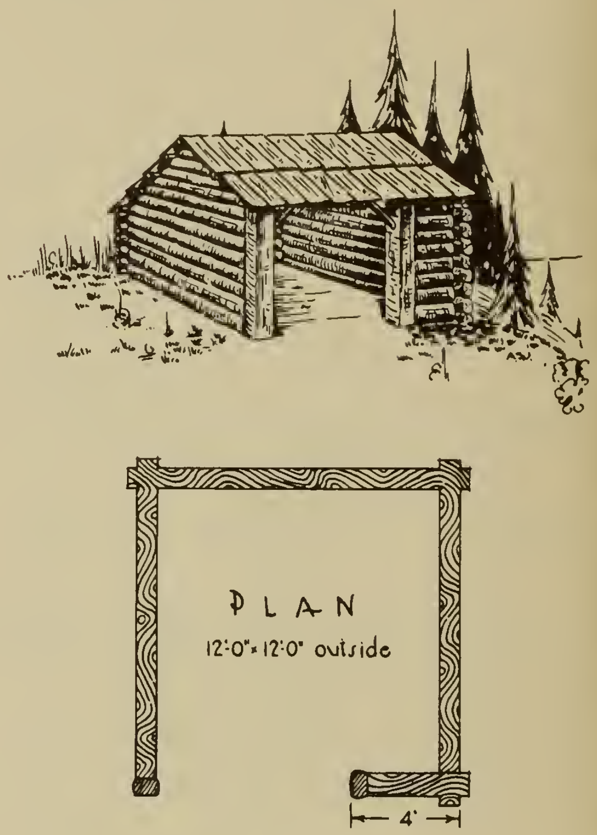
Figure 41-XI. Mine Survey

Refer all elevation data to a 5500 foot elevation Bench Mark located near the entrance to the mine.

Group 23-XI. Some Miscellaneous Applications

1. Scale 1/4" = 1'-0". Use a double space.

Dimensions for overnight shelter, Figure 42-XI: Size 12'-0" x 12'-0" over-all. Ridge pole 9'-0" high and 4'-0" from front. Front eave 6'-6" high. Rear eave 4'-0" high. Draftsman should supply any missing details or dimensions. See Ch. XVII for architectural details. Make the following dimensional drawings: (1) Plan. (2) Front elevation. (3) End elevation. (4) What is the pitch of each roof? (5) Give a bill of material. Lodge poles are used and will average 8" in diameter. (6) Reproduce the pictorial sketch of the shelter.



BILL OF MATERIAL

| Name | Material | Req'd. |
|---|---|---|
| 10"×14'-0" Logs | Lodge Pole | 30 |
| 6"×14'-0" Logs | Lodge Pole | 7 |
| ½"×8"×36" Shakes | Cedar | 220 |
| 6d. Nails | Wire | 3 lb. |
| 60d. Spikes | Wire | 10 lb. |

Figure 42-XI. Overnight Shelter

2. Scale 1/4"=1'-0". Use a double space. Copy the plan of Figure 43-XI, and draw (1) a front elevation, (2) end elevation, and (3) make a free-hand pictorial sketch of the log cabin. The side walls are

7'-6" above the floor. Pitch = 1/3. (4) Give a bill of material (see Figure 42-XI). The draftsman is to furnish missing details and dimensions. The plan, front, and end elevations are to be dimensioned. Lodge poles are to be used and will average 8" in diameter. See Chapter XVII for architectural details.

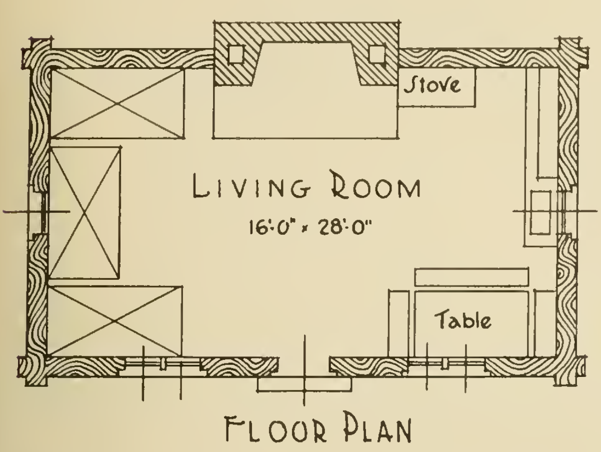


Figure 43-XI. Plan for a One-room Log Cabin

3. Scale 1/8" = 1'-0". Use a double space. Make a plan and other necessary drawings of the culvert crossing of Figure 44-XI. Determine: (1) The lines of intersection between the side slopes of the highway and the side slopes of the drain. (2) Two of these lines will meet in the head wall of the culvert (inside face). What is the length of the culvert span? (3) Choose a point in the north bank of the drain, just east of the intersection. A guy line is erected here. Slope of line is 4 : 12 with a bearing of S 15° E. What angle (give degrees) does the line make with the drain bank? (4) What is the angle (give degrees) between the south bank of the drain and the east slope of the highway taken east of the intersection?

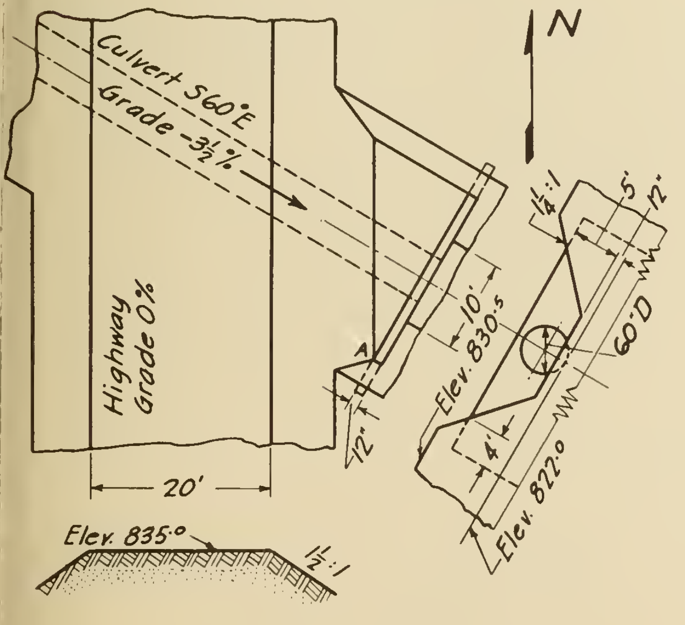


Figure 44-XI. Culvert Crossing

4. Scale 1/8" = 1'-0". Use a double space. The construction illustrated in Figure 45-XI is typical of retaining wall work. The wing walls end at M, the point where the three following surfaces intersect:

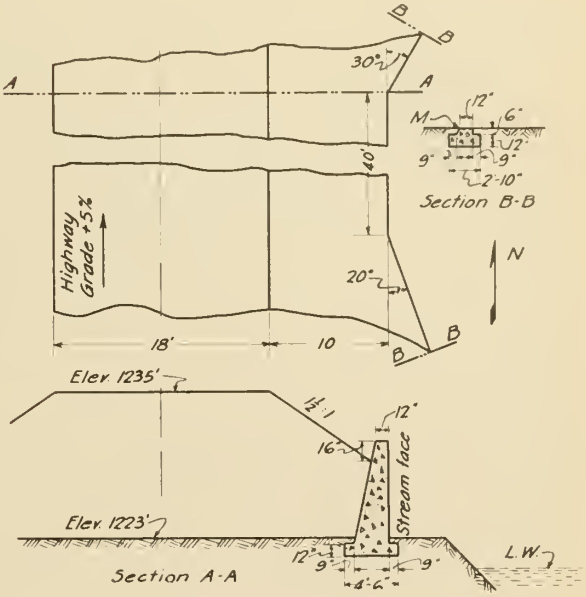


Figure 45-XI. Retaining Wall Construction

(a) natural ground surface (taken as level), (b) the inclined face of the retaining wall (bank face), and (c) the east side slope of the highway. Determine: (1) Length in feet of each wing wall. (2) The cubic yards of concrete in the entire retaining wall. (3) Angles in degrees which each wing wall makes with the east slope of the highway.

5. Scale 1" = 100'. Use a double space. Copy just that part of the map, Figure 46-XI on the following page, which shows the 90° intersections of Jackson Street with Oak and Grove Avenues. AB and BC are the center lines of two water pipes with grades as shown. Determine: (1) Angle ABC in degrees. (2) Angle ACB is 45°. What is the length in feet of BC, AB, and AC? What

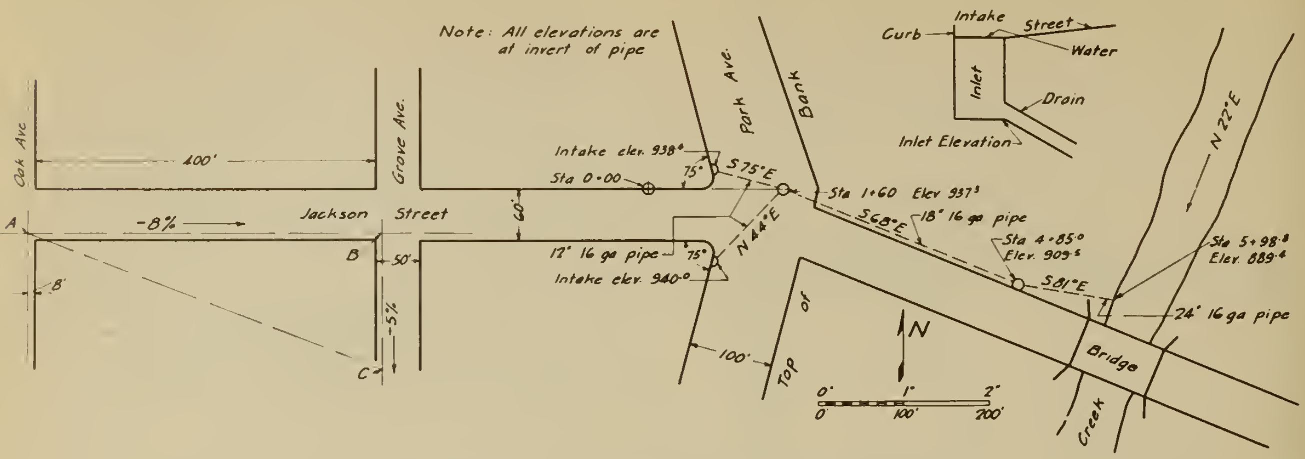
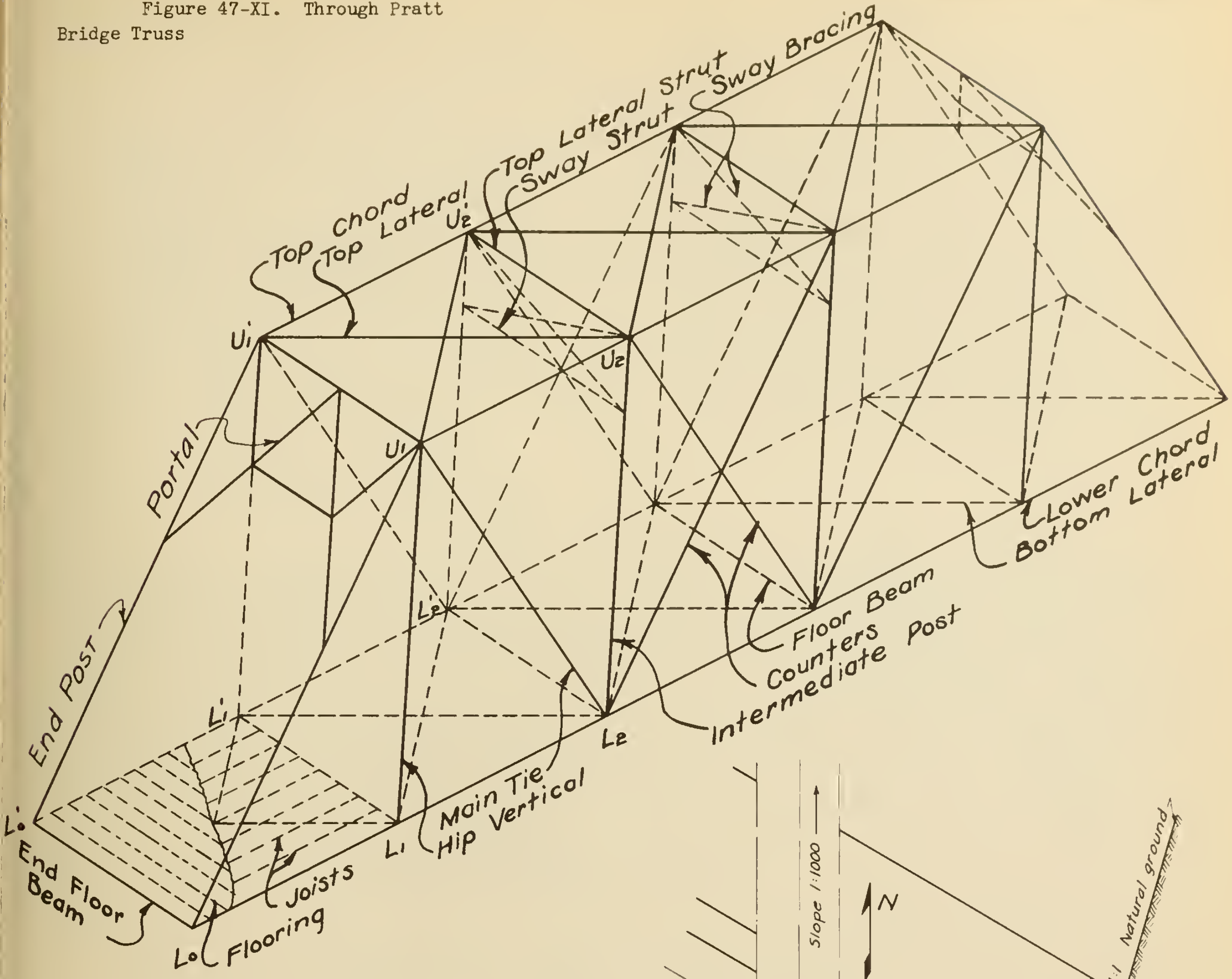


Figure 46-XI. Street Location and Intersection

is the angle in degrees of CAB? (3) Consider the grade of line BC as zero. From C construct a line CP, grade 10% falling eastward, and bearing N 38 1/2° E. From B construct a line BM, grade 10% falling eastward. These two lines intersect to the east of BC. Find the point of intersection of the lines, the length of each line in feet, and the angle in degrees between the two lines.

6. Scale 1" = 100'. Use a double space. Reproduce that part of the map which lies between the west bank of the creek, Figure 46-XI, and the east property line of Grove Avenue. Determine: (1) Slope of each of the four sections of drain pipe indicated in the drawing. (2) List a bill of material for the pipe only.
7. Scale 1/4" = 1'-0". Use a double space. A through Pratt bridge, Figure 47-XI on the following page, is to be constructed across the creek at the intersection of Jackson Street, Figure 46-XI. Total span 100'. Total height 30'. Over-all width 20'. Using the left half of the structure represented by a line drawing, show: (1) A plan, end elevation, and elevation looking upstream. (2) What is the true length and slope of the end chords, main ties, the counters, and the longest members of the portal? The longest members of the portal meet the end chord, $U_1 - L_0$, at a point 2/5 $U_1 - L_0$, measured from $U_1$. Other distances are to be taken as suggested in the drawing. (3) Make a normal view of the portal, end chords, end floor beam, and $U_1 - U_1'$.
8. Scale 1" = 20'. The size of blocks shown in Figure 46-XI is 300' x 400', with 6 lots 150 feet deep facing on Jackson Street. Jackson Street has a downgrade eastward of 10% at the intersection with Park Avenue. Park Avenue, north of Jackson, had a downgrade southward of 12 1/2%. The corner lot north of Jackson and west of Park is to be leveled off at an elevation of 955 feet so that the two terraces will have a slope of 1 1/4 : 1. Locate lines representing the limiting edges, on Jackson and Park, of the level part of the lot. Elevation of the ground at the intersection of the property lines on Jackson and Park is 944 feet.
9. Scale 1/8" = 1'-0". Use a double space. Reproduce the drawing of Figure 48-XI shown on the following page. The slope of the flume, drain, and berm are so flat they can be taken equal to zero without introducing serious errors in this problem. The east pile of the south flume bent strikes the slope of the drain at the edge of the water. The west pile of the north bent comes within 12" of the north edge of the berm. (1) What is the length in feet of the span? (2) The piles have an average penetration of 5'. What is the length in feet of each pile? (3) Give the angle in degrees which each pile makes with the side slopes of the drain.
10. Scale 1/8" = 1'-0". Use a double space. The slope of sewer above D and below C is S = 4 : 1000, as indicated in Figure 49-XI, on page 117. The line is siphoned--D to C --under a concrete-lined canal. Diameter of pipe is 20". Determine: (1) The length of pipe from D to C. (Includes all four pipe bends.) (2) Slope in degrees of the sides of the siphon. (3) Angle in degrees between the main sewer line and the sides

Figure 47-XI. Through Pratt Bridge Truss



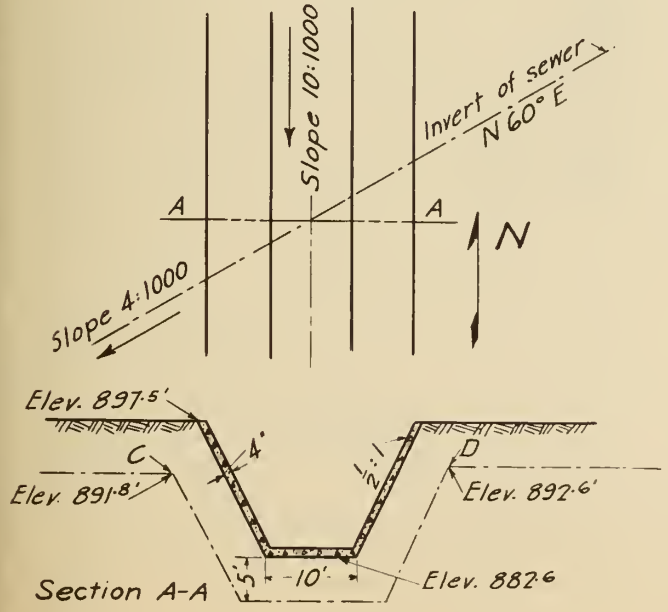


Figure 49-XI. Canal-Sewer Crossing

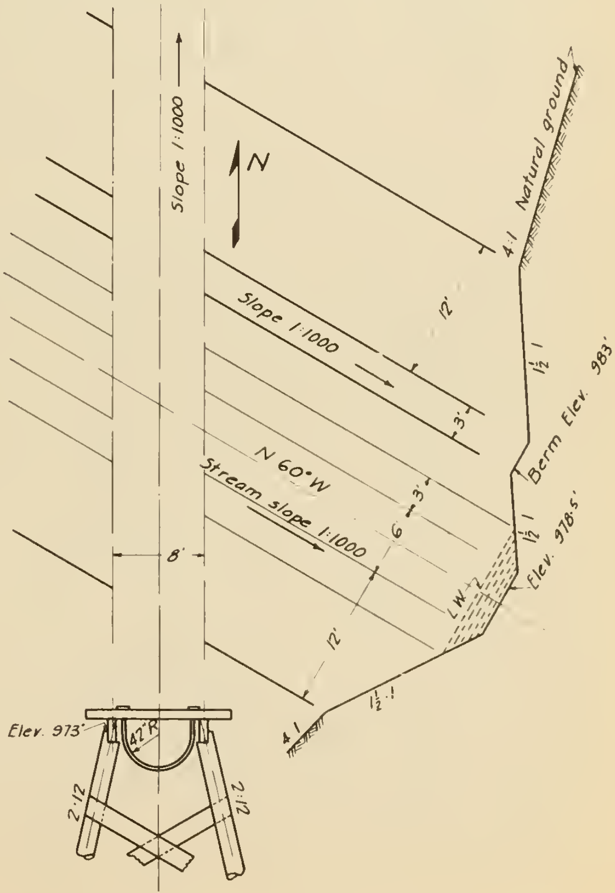


Figure 48-XI. Flume-Drainage Crossing

of the concrete lining. (4) Points where the sewer line would pierce the sides of the canal lining if the line had been run through. (5) The four turns of the siphon are constructed of special elbows with radii of 6 feet. What are the angles of the elbows? What are the sweep angles? A sweep angle subtends a circular arc.

11. Scale 1 1/2" = 1'-0". In the gusset plate layout of Figure 50-XI, certain details and dimensions are omitted. Reproduce the drawing and supply the missing data marked x. Rivet lines marked X at ± 3" = 18" will have to be adjusted. Maximum spacing of rivets 3". Span = 30'. See Figure 59-XVII, for wood truss construction of this type.

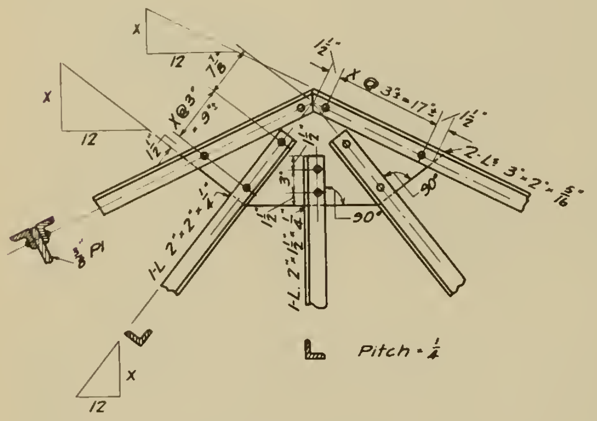


Figure 50-XI. Gusset Plate

12. Scale 1" = 1'-0". Consider the Pratt roof truss of Figure 59-XVII to be constructed of angle irons similar to the type shown in Figure 50-XI. Design a gusset plate for joint $U_3$.
13. Same as exercise 12 above but design a gusset plate for joint $L_0$.
14. Same as exercise 12 above but design a gusset plate for joint $U_1$, Pratt bridge truss, Figure 47-XI.
15. Same as exercise 12 above but design a gusset plate for joint $L_0$, Pratt bridge truss, Figure 47-XI.
16. Scale 3" = 1'-0". Use a double space. Reproduce the three principal views of Figure 51-XI. Draw normal views of (1) the 4" face of one of the hip rafters and (2) the two bevels (cuts) where the rafter joins the ridge pole. Also, (3) a normal edge view (2" face) of the rafter. And, (4) what is the pitch of the roof? In addition to the normal views of the 2" edge and 4" face of the timbers, a mechanic will want normal views of the bevel faces so he can obtain the "angle of cut" for timbers.

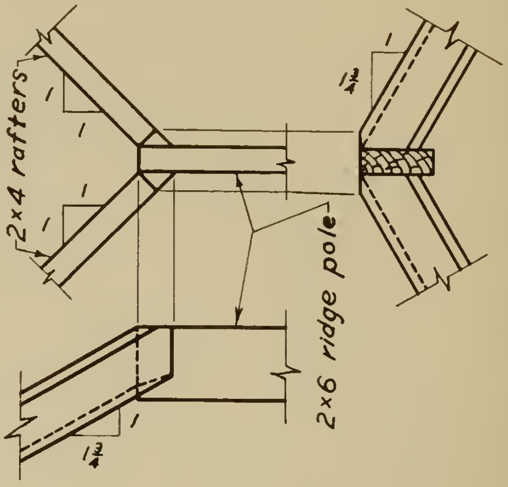


Figure 51-XI. Hip Rafter and Ridge Pole Construction

17. Scale 3" = 1'-0". Use a double space. Reproduce the three principal views of Figure 52-XI. (1) Draw the normal views of (a) the 4" face of one of the jack rafters and (b) the bevels (cuts) at the lower end of the jack rafter. (2) Draw the normal views of (a) the 4" face of the hip rafter and (b) the bevels (cuts)

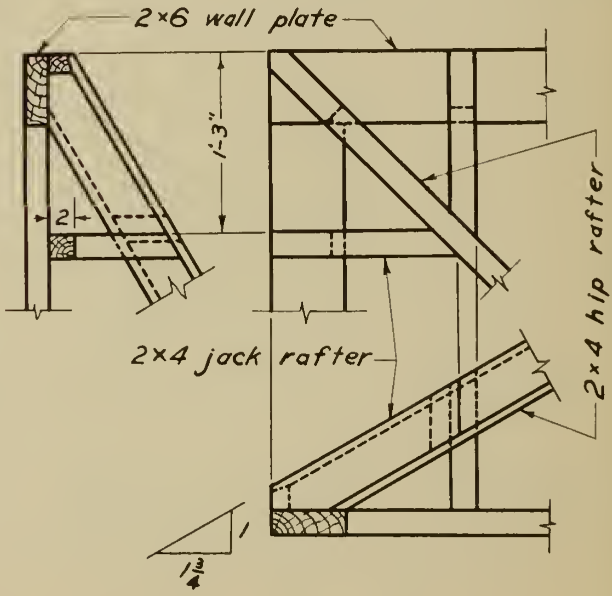


Figure 52-XI. Hip Rafter, Jack Rafter, and Wall Plate Construction

at the lower end of the hip rafter. Also, (3) a normal edge view (2" face) of the (a) jack rafter and (b) hip rafter. And (4), what is the pitch of the roof? In addition to the normal views of the 2" edge and 4" face of the timbers, a mechanic will want normal views of the bevel faces so he can obtain the "angle of cut" of the timbers.

18. Scale 1/2" = 1'-0". Space 8" x 12". Reproduce the two elevation views of the reinforced concrete bridge stringer (inside stringer) of Figure 53-XI. Make a bill of reinforcing steel for one inside stringer. Slab steel should not be listed with stringer steel. Make a tracing on cloth of the two views and make a bill of material.

If a guide pulley were placed in the system, the belt on pulley T would have to be reversed, i.e., the belt should then run directly from a to b.

To draw the guide pulley: Select a point P, preferably midway between the two pulleys, which is common to the center planes of both pulleys. From P draw a pitch line tangent to the main pulleys. The two tangent lines just constructed will form the center plane of the guide pulley.

The faces of the pulleys are taken as 6" without crowns. Shafts have 2" D. Belt is 1/4" x 4". Pulley M has 20" D. Pulley N has 10" D. Guide pulley to have 16" D. Center lines of shafts are 6' apart. (1) Draw the guide pulley and

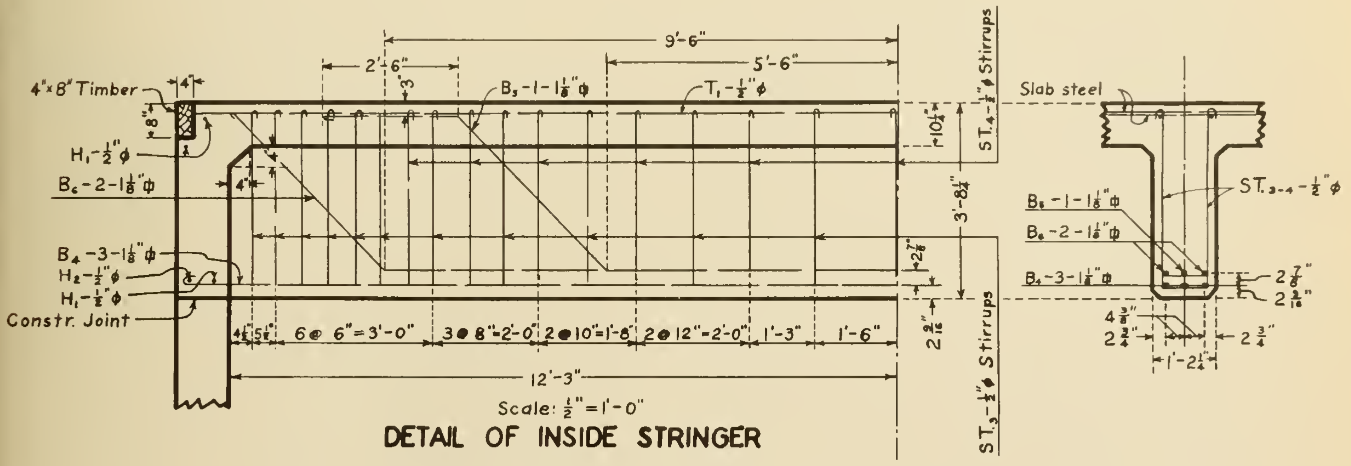


Figure 53-XI. Reinforced Concrete Bridge Stringer

19. Scale 1" = 1'-0". The proper alignment for two pulleys is shown in Figure 54-XI for a quarter turn non-reversible belt. The belt will run in the direction indicated without the aid of a guide pulley, but in order to reverse the direction of rotation a guide pulley will have to be placed on the slack side of the belt. A plane through the center of the receding pulley, perpendicular to the pulley axis, must include the tangent point a, the point where the pitch line leaves pulley M. If pulley N is in such a position on shaft T that a plane through the middle of its face contains point a, the belt will run properly onto pulley N. Similarly, the pitch line of the belt leaves pulley N at b, and M is so located that on shaft S a plane through the middle of its face contains b.

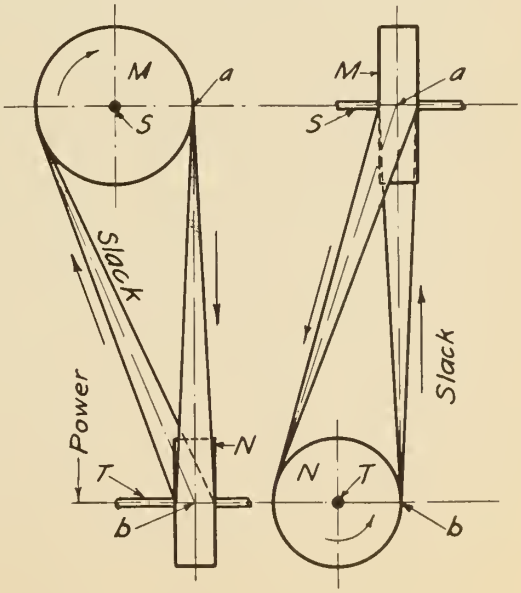


Figure 54-XI. Quarter Turn Non-reversible Belt

its shaft. (2) What length of belt will be needed?

20. Scale 1" = 1'-0". Locate point A toward the lower left-hand corner of the problem space. Point B is 2'-0" due north of A and on the same level with A. Point C is 1'-6" east, 0'-6" below, and 1'-3" north of A. Point D is 2'-9" directly above and 1'-3" north of A. An 18" pulley is located on the center of shaft AB and a 24" pulley is located on the center of shaft CD. Other data as given in Exercise 19. (1) Construct 20" guide pulleys so the belt will run in either direction. (2) What length of belt will be needed?

21. Scale 1" = 1'-0". Locate point A toward the lower left-hand corner of the problem space. Point B is 2'-0" east and 2'-0" north of A, and on the same level as A. Point C is 5'-0" east of A, 1'-3" below, and 3'-6" north of A. Point D is 5'-0" east, 1'-3" below, and 5'-6" north of A. A 12" pulley is located on the center of shaft AB, and a 24" pulley is located on the center of shaft CD. Other data as given in exercise 19. (1) Construct 18" guide pulleys so the belt will run in either direction. (2) What length of belt will be needed?

# CHAPTER XII

## SURFACES, INTERSECTIONS, AND DEVELOPMENTS

1-XII. A structure is defined by the surfaces bounding it, and the defining surfaces are limited by certain lines. These lines, in turn, are formed by the intersection of the surface edges of the structure. Reference is here made to the elementary structures. The cube, for instance, is bounded by six surfaces, and these surfaces intersect to form twelve lines which are called edges of the cube. A cylinder has three surfaces and two lines of intersection or edges. A cone has two surfaces and only one line of intersection, while an annular torus and a sphere each have but one surface and no intersecting lines or edges, unless intersected by another surface. These lines of intersection and the defining lines of curved surfaces, such as the outlines of cylinders, cones, spheres, and the like, are located on a drawing as a means of describing an object.

Since the more complicated structures are composites of the simpler ones, i.e., the prism, pyramid, cylinder, cone, sphere, torus, and others, the treatment of the intersection and development of surfaces in this chapter will be confined to illustrations and problems of the less elaborate objects.

2-XII. Structural Elements Classified. Since a structure is limited by the bounding surfaces, and surfaces in turn are defined by other geometrical elements, it might be well to analyze the structure into its various elements in order better to understand the method of representing objects in drawings. The geometrical elements of a structure have been defined, Figure 1-IV and Article 1-XI.

The point has no dimensions but has position. The line has only one dimension (length) and has direction. A line may be generated by the motion of a point. The nature of the line so generated will depend upon the physical laws governing the motion of the point. The line might be straight or curved. If curved, it might be single-curved or double-curved (space curve) and subclassified as shown. A surface has area (two dimensions) and direction but has no thickness. It can be generated by the motion of a line. If generated by a straight line, the surface is said to be ruled. A double-curved surface is generated by a curved line. It should be noticed that ruled surfaces are further classified as plane, single-curved, and warped. A double-curved surface is composed of curved line elements, while a ruled surface is composed of straight line elements.

These elements and structures are classified in Figures 1-XII and 2-XII.

3-XII. Surface Intersections and Piercing Points. In order to find the line of intersection between two surfaces, i.e., the line which is common to both surfaces, a sufficient number of lines (or elements) are established which will fix or determine each surface. The points where the lines of one surface pierce (or intersect) the other surface are established, Figure 3-XII, page 124, points 5, 6, 7, and 8. The line connecting the piercing points is the line of intersection between the surfaces as line 5-7, etc. Numerous methods are employed for determining piercing points and lines of intersection. In locating a piercing point the edge view of a surface is necessary. Usually an edge view of one of the surfaces of the structure can be located in the drawing. The point where the line crosses the edge view is the piercing point in that view. In Figure 3-XII, surface ACD is seen as an edge view in the top. Line 2-8 crosses the edge view at point 8 (top). Point 8 is then located in the front view on line 2-8 directly below point 8 in the top. Other points are located similarly. It should be noticed that the line connecting points 5 and 7 is the line of intersection between surfaces 1-3-5-7 and ACB, but surface 1-2-7-8 intersects two other surfaces, i.e., surfaces ACD and ACB. The line of intersection is broken. It is not the straight line connecting 7 and 8 but consists of lines 7-9 and 9-8. Point 9 is the piercing point of line AC and surface 1-2-7-8 and is first located in the top where 1-2-7-8 is an edge view. The other lines of intersection are located similarly.

Elements of Structures
- Point
- Line
  - Straight
  - Curved
    - Plane curves
      - Circle
      - Ellipse
      - Parabola
      - Hyperbola
      - Spirals
      - Involutes
      - Cycloids
    - Space curves
      - Helix:
        - cylindrical
        - conical
- Surface
  - Ruled
    - Plane
      - Prism
      - Pyramid
      - Polyhedron
    - Single-curved
      - Cone
      - Cylinder
      - Convolute
    - Warped
      - Hyperbolic paraboloid
      - Conoid
      - Helicoid
      - Hyperboloid of revolution
      - Cylindroid
      - Warped cone
  - Double-curved
    - Sphere
    - Ellipsoid
    - Paraboloid
    - Hyperboloid of two nappes
    - Annular torus
    - Surfaces of revolution
    - Serpentine
    - Springs

Figure 1-XII. Geometrical Elements of Structures Classified
(See also Figure 1-IV)

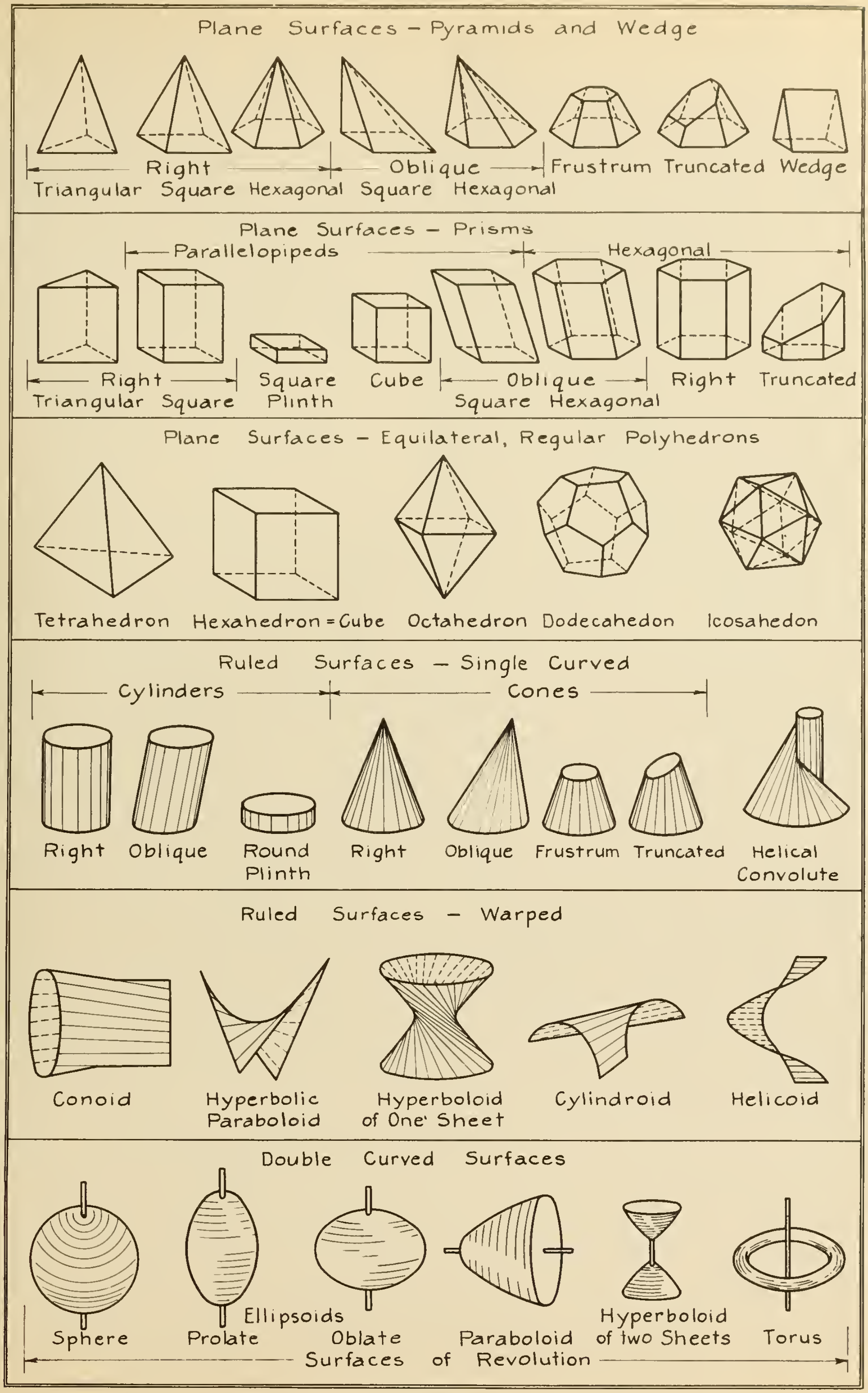


Figure 2-XII. Geometrical Classification of Solids and Surfaces

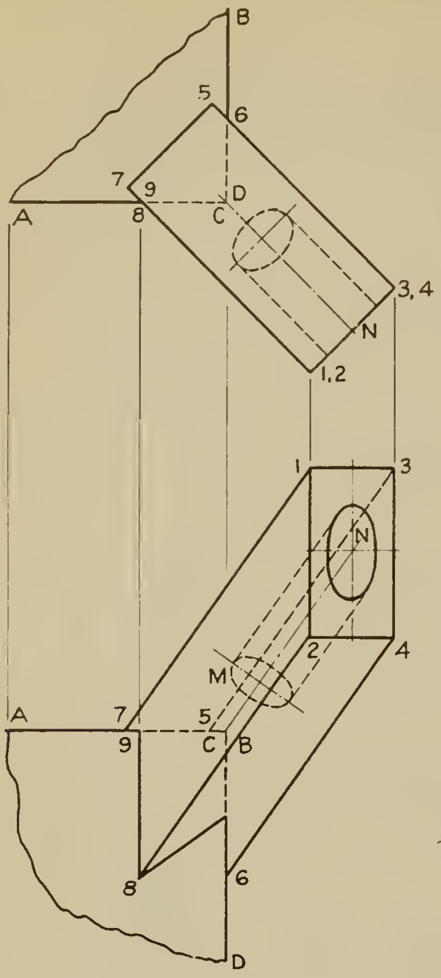


Figure 3-XII. Staff Socket

Plane Surfaces

4-XII. Prism. A solid bounded by planes is called a polyhedron. A polyhedron is termed a prism when two faces are congruent polygons in parallel planes and when the other faces are parallelograms.

When an oblique structure is not specified, a right structure is understood.

To Find the Piercing Points and the Lines of Intersection of Two Prisms: The slicing plane method is used in locating the lines of intersection of the two prisms in Figure 4-XII. The frontal planes X-X, Y-Y, and Z-Z are drawn through the lines g9, c3, and f6 respectively. These planes cut frontal lines from the square prism and are obtained in the front view by dropping points 9, 5, and 6 from the top view to the front view, as shown, thus locating piercing points 9, 5, and 6, in the front view. Line c3 pierces the triangular prism at points 7 and 8. The points are located as follows: Plane Y-Y (passing through lines c3) cuts surface g e f in the top view at points m and p. These points are located in the front view and are then carried to the left, from the front view, until line c3 is crossed, thus locating piercing points 7 and 8. Connect in turn points 5, 8, 9, 7, 6, and 5, and the lines of intersection are located.

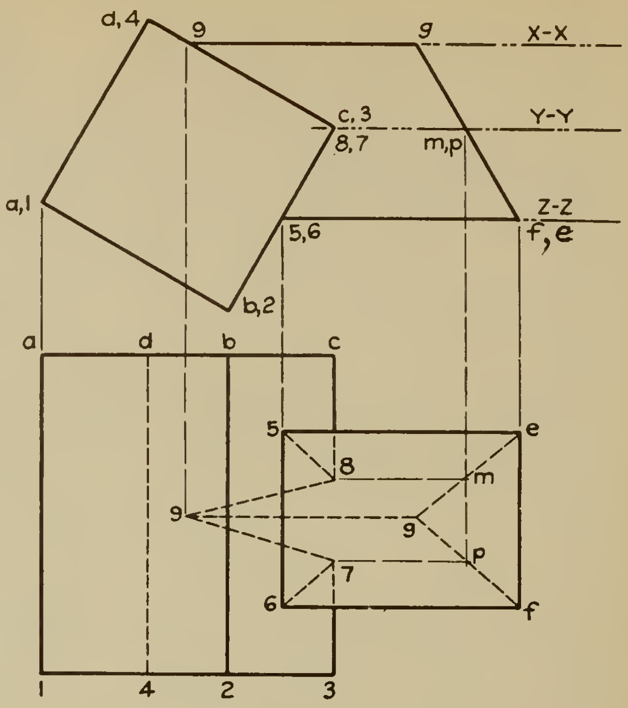


Figure 4-XII. Intersecting Prisms

For a further illustration of the slicing plane method, see Figure 13-XII.

5-XII. Pyramid. A pyramid is a polyhydron, Article 4-XII, of which one face, called the base, is a polygon of any number of sides and the other faces are triangles having a common vertex.

To Find the Lines of Intersection Between an Oblique Plane and a Pyramid in Oblique Position: The oblique plane RST cuts the right pyramid ABCV, Figure 5-XII, page 125, along lines 1-2, 2-3, and 3-1, as shown. Base ABC is an equilateral triangle. The pyramid is also in oblique position. It will be necessary to find the line of intersection between the following surfaces: (1) AVB and RST, (2) AVC and RST, (3) BVC and RST. An edge view of one plane in each combination will be necessary. As RST appears in all three combinations, an edge view of this plane was obtained in order to save time and labor. Any one of the three primary auxiliaries could have been used. The auxiliary elevation was chosen.

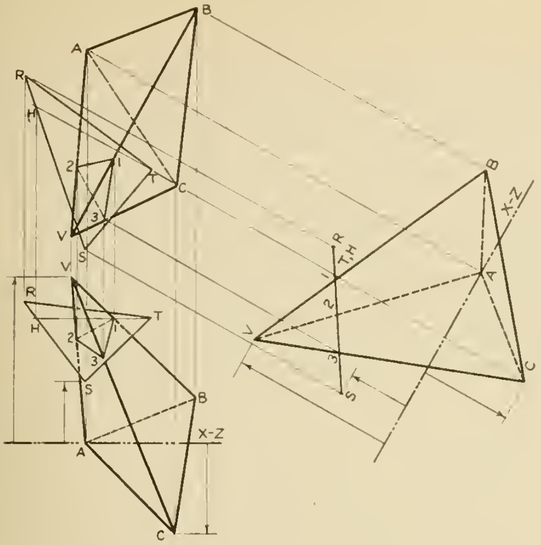


Figure 5-XII. Intersection of a Pyramid and a Plane

The procedure is as follows: Draw TH, a horizontal line. Draw the auxiliary rays from the top view in a direction parallel to the top view of TH. Draw the X-Z reference plane, passing through point A in the front and auxiliary views. In both views the observer is looking into the top. Point A is on the horizontal reference plane. C is below the plane in both cases. All other points are above the plane. Arrows are drawn to illustrate the method of locating points V, S, and C. Plane RST is a line in the auxiliary, indicating that RST is an edge view, as was desired. The required piercing points, 1, 2, and 3 lie at the intersection of line RST and the three lines leading to the vertex V, i.e., BV, AV, and CV, respectively. Points 1, 2, and 3 are then located on their corresponding lines in the top and front. When the points are joined in successive order, the corresponding lines, 1-2, 2-3, and 3-1, are the lines of intersection between plane RST and the pyramid.

### Surface Developments

6-XII. The Development. The development of surfaces of structures is greatly emphasized in engineering drawing. A great many articles are manufactured from sheet metal, rather than from cast metal, and the practice seems to be increasing. The sheet metal articles are usually lighter, stronger, and less expensive to manufacture than are similar articles that are cast. Other sheet materials are extensively used, such as fiber, paper, and the like.

If an article is to be manufactured from sheet material, a pattern or development is first made. The pattern represents the surfaces of the object. When the blank is cut out, creased along the edges, and folded properly, a model of the object will be produced. When developing, the surface of the pattern next to the observer represents the surface of the object, i.e., the extreme ends of the pattern should be brought up and toward the observer when the model is put together.

After the pattern has been formed and cut out, it is laid on the sheet material, held in place by weights, and points are pricked through the paper into the sheet material by means of a sharp-pointed tool or instrument. The pattern is then removed, and the desired lines are scratched on the sheet material. The blank article is then cut from the sheet material and folded by means of a brake, stretched by means of dies or by hammering, or is curved by means of rolls in order to obtain the desired form. After the blank has been brought into shape, the proper edges are joined by seaming, riveting, welding, or soldering. Arc welding is coming into more extensive use all the time. The neat development is shown by solid lines in the drawing, and the allowance for seams, if indicated at all, is represented by dotted lines drawn outside the limiting lines of the pattern. Three seams should not meet at a point. This makes very difficult construction. The blank should be cut on the shortest line, thus obtaining the least amount of seaming. If the development is made symmetrical, only half of the pattern need be cut out. If the material from which the article is to be made is 20 gage (0.0375 inch) or thinner, the thickness of material when making the development need not be taken into consideration. If thicker than 20 gage, allowance should be made for shrinkage of the material when the blank is bent or rolled into shape. The allowance made is usually three or four times the thickness of the material. This allowance should be distributed over the entire pattern rather than added to one edge. Often the development of a surface halfway between the two outside surfaces of the object is made as a means of compensating for excessive thickness of material.

Since consecutive elements of plane and single-curved surfaces intersect, the development of surfaces in these two classifications can be made accurately. Consecutive elements of warped surfaces do not intersect. Therefore, the development of warped surfaces can only be approximated, after which the blank is stretched or hammered into shape.

The elements of these three classes of surfaces (ruled surfaces) are straight lines, Figure 1-XII.

Since the elements of double-curved surfaces are curved lines, their developments have to be approximated. Maps of large areas and navigators' charts are approximations on a flat surface of a spheroid or an ellipsoid of revolution. Ball covers, dome developments, and the like, are approximated, and the material is then stretched into shape.

7-XII. Prism. The hexagonal prism of Figure 6-XII is cut by a plane perpendicular to a frontal plane, 45 degrees with a top plane and 45 degrees with a side plane. The truncated section is shown. The lower base being perpendicular to the axis, it will form the straight line 1-2-3-4-5-6-1 when the prism is rolled out as indicated, and is known as the base line. The distances 1-2, 2-3, etc., are equal in length and equal to the sides of the lower base, which is a regular hexagon. At these points on the base line perpendiculars are erected representing the edges of the prism. The true lengths of the edges of the prism are obtained from the front view and are laid off on the perpendiculars just erected in the development. These true length distances may be transferred with the dividers or drawn straight across as indicated. In order to complete the development, the lower and upper bases are attached, being transferred from the top view and the auxiliary view, respectively, by the triangulation method. This method is indicated in the auxiliary view and the development of the top base. True lengths of the edges of the upper base could have been obtained by revolving the lines instead of drawing the auxiliary.

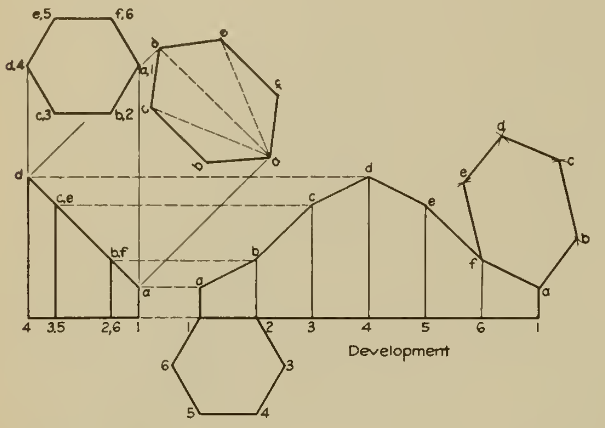


Figure 6-XII. Development of a Right Hexagonal Prism

8-XII. Oblique Prism. The axis of an oblique prism makes an acute angle with the bases.

To Develop the Lateral Surface of a Triangular Oblique Prism: Given: the front and top views of triangular prism in oblique position, Figure 7-XII. Required: a development of the lateral surface (omitting both bases) of the prism by the triangulation method. The development is opened along line BE, and CF is used as a reference line. A construction diagram from which certain true lengths of lines are obtained is shown in the upper right-hand part of the drawing. The construction of this diagram is based on the theory of revolution as follows: Erect a line, MN, equal to the distance h obtained from the front view. At one end of MN draw a perpendicular, NO. With N as the origin, lay off on NO a distance equal in length to the top view of the line in question. The hypotenuse of the right-angle triangle just constructed is the true length sought.

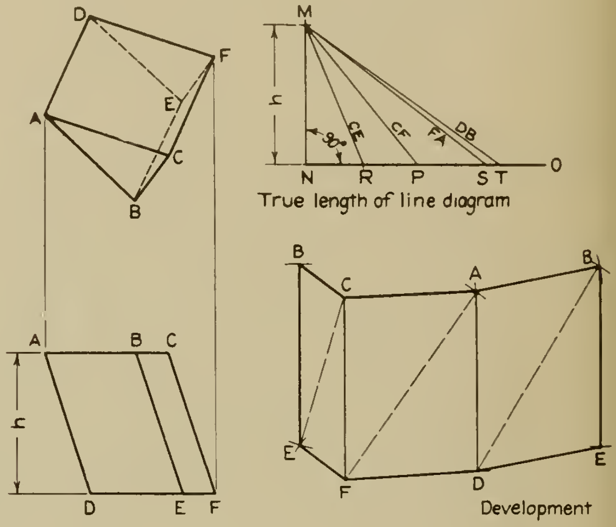


Figure 7-XII. Development of Triangular Oblique Prism

To make the development: Draw MN and NO as indicated. Lay off NP on NO equal to the length of the top view of CF. Connect M and P, which is the true length of CF. Proceed as before and find the true lengths of the lines CE, FA, and DB. Obtain the true length of line CF from the diagram and draw it as the first line of the development. With C as a center and the true length of CE as a radius, sweep an arc. With F as a center and the true length of FE as a radius (obtained from the top view) sweep an arc. Point E lies at the intersection of these two arcs. With C as a center and the top view of CB as a radius, sweep an arc. Through E draw a line parallel to CF. The intersection is point B. The other surfaces are developed in a like manner, as indicated. The three lateral surfaces form parallelograms. Oblique prisms can be developed by the method illustrated in Article 13-XII.

9-XII. Pyramid. Development of the lateral surface of a truncated right, hexagonal pyramid is shown in Figure 8-XII. The auxiliary view shows the true size and shape of the upper base, while a true description of the lower base can be found in the top view. A complete development of the truncated pyramid is obtained when these two bases are properly attached. The object is cut at the mid point of its axis by a plane making 45 degrees with the lower base and perpendicular to a frontal plane.

Front and top views are shown. A true length of one of the edges of the pyramid, V1, is obtained by revolution and is represented by line V1'. Edges V2 and V5 are profile lines. To locate points b and e, a side view of one of the lines, say V2, can be obtained, point b drawn from the front view to the side view, thence to the top view. Or line Vb in the front view can be revolved backward, as indicated in the drawing, and point b in the top view thereby located.

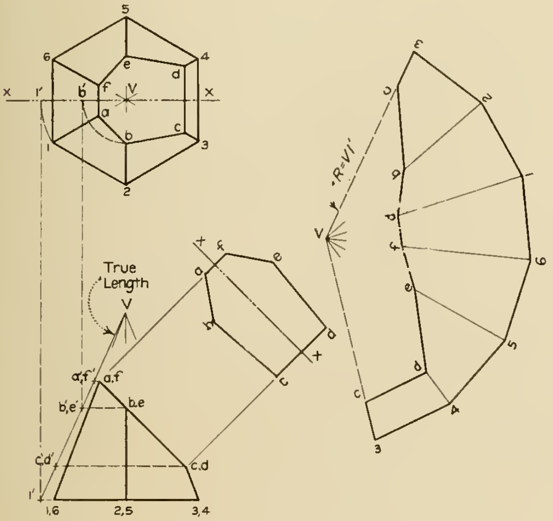


Figure 8-XII. Development of Right Hexagonal Pyramid

To make the development: Lay down the base line V3. Using V1' as a radius, sweep an arc. Lay off on the arc just constructed lines 3-4, 4-5, etc., obtained from the top view. Draw in the edges of the pyramid V3, V4, etc., and on the edges just constructed, lay off distances 3c, 4d, etc. These last distances are equal in length to lines 1'c, 1'd, etc., obtained in the front view, and are true lengths of the truncated edges of the pyramid.

10-XII. Oblique Pyramid. The front and top views, and development of the frustum of an oblique pyramid are shown in Figure 9-XII on the following page. The altitude h is laid off on line OM of the true length diagram, thus locating points a to f inclusive. On OP, the top views of lines a-1, b-2, etc., are laid off, thus locating points 1, 2, and others. The true lengths can now be drawn. The development was made by triangulation. The development could have been made by locating the vertex V and the various edges V1, V2, etc., and laying off on these lines true lengths a-1, a-2, and other lines, as illustrated in Figure 8-XII.

## Single-Curved Surfaces

11-XII. Ruled Surfaces. A ruled surface is generated by a moving straight line called the generatrix. There are three types: (1) planes, (2) single-curved surfaces, and (3) warped surfaces. See Figure 1-XII.

A single-curved surface, having straight line elements, is a ruled surface. Two or more consecutive elements will therefore intersect. Since it is a curved surface, no three consecutive elements will lie in the same plane. The single-curved surface is developable, since consecutive elements intersect. This type of surface is composed of: (1) cones, (2) cylinders, and (3) convolutes.

12-XII. Cone. A cone is a solid formed by a straight line generatrix which constantly touches a fixed plane curve directrix and passes through a fixed point, called the vertex, not in the plane of the curve. Two nappes are therefore formed.

If the directrix is an open curve, an open cone is generated. When a circle is used as a directrix, a circular (closed) cone is formed. All elements intersect.

The conic surface is called the lateral surface. A plane cutting all elements is called the base. When the axis is perpendicular to the base a right cone is obtained. If it is oblique to the base, an oblique structure is formed.

The development of a truncated right circular cone may be made as outlined in Article 9-XII, Figure 8-XII, after the elements have been drawn. This method is very similar to the one outlined in Figure 10-XII on the following page. The object is cut at the mid point of its axis by a plane, making an angle

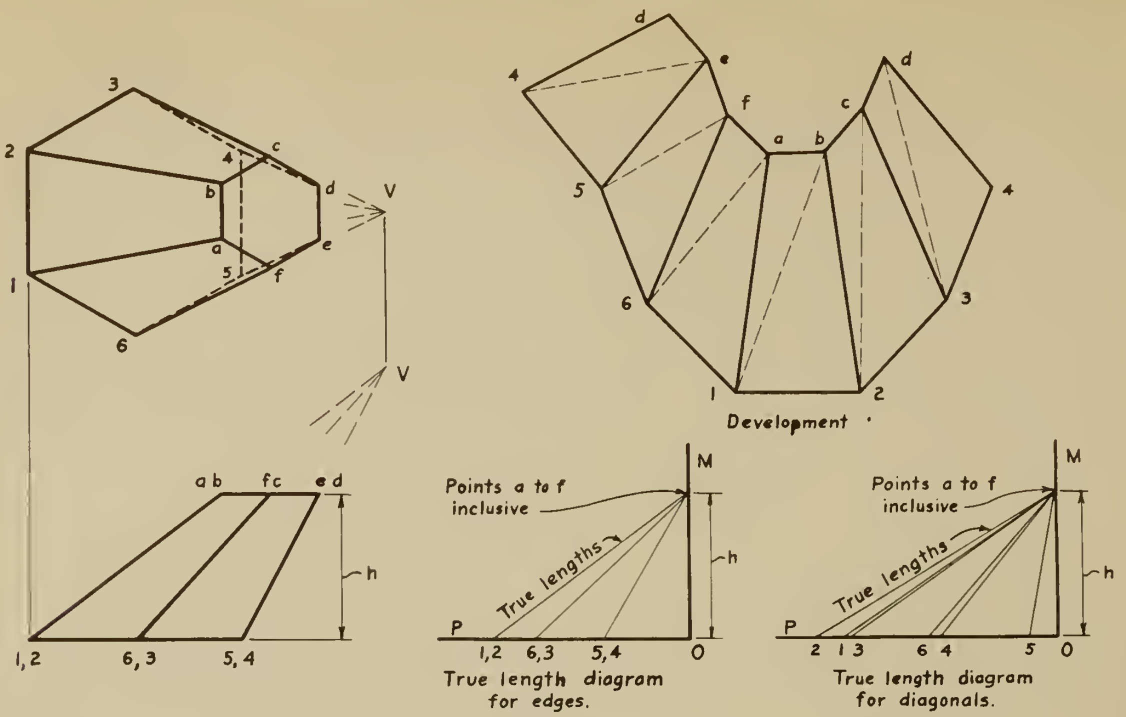


Figure 9-XII. Development of Oblique Pyramid

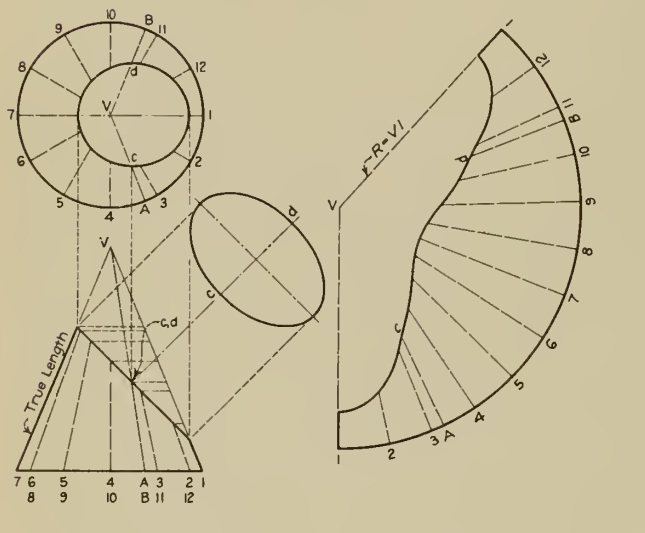


Figure 10-XII. Development of Right, Circular, Truncated Cone

of 45 degrees with the lower base and perpendicular to a frontal plane. After the cone has been truncated, the ellipse in the top view representing the upper base must be drawn. Elements 4V and 10V are profile lines. In locating the point where these two lines are cut by the ellipse, a side view might be drawn of one of them, say 4V, or the method of revolution could be employed as illustrated in Figure 8-XII.

The auxiliary view shows the true size and shape of the upper base, while a true description of the lower base can be found in the top view. A complete development is obtained when these two bases are attached. The length of the minor axis in the auxiliary can be obtained from the top after a sufficient number of points have been located and the ellipse has been drawn. Or the major axis might be bisected in the front view, and two elements, AV and BV drawn through the point just located (which is the minor axis cd). Where the ray from cd in the front view crosses the elements, AV and BV in the top will locate cd in the top, which is the true length of the minor axis.

The development of the truncated object is shown in Figure 10-XII, and is made as outlined in Article 9-XII.

13-XII. Oblique Cone. The front and top views, and development, of an oblique cone is shown in Figure 11-XII on the following page. The oblique cone is used in tangent surfaces and sheet metal work. The development is symmetrical about line V6. The shortest element VO is obtained from the top view (or by revolution). Point 1 is located by sweeping arcs: (a) O1, obtained from the top view, and (b) V1, obtained from the true length diagram shown in the top view (to be

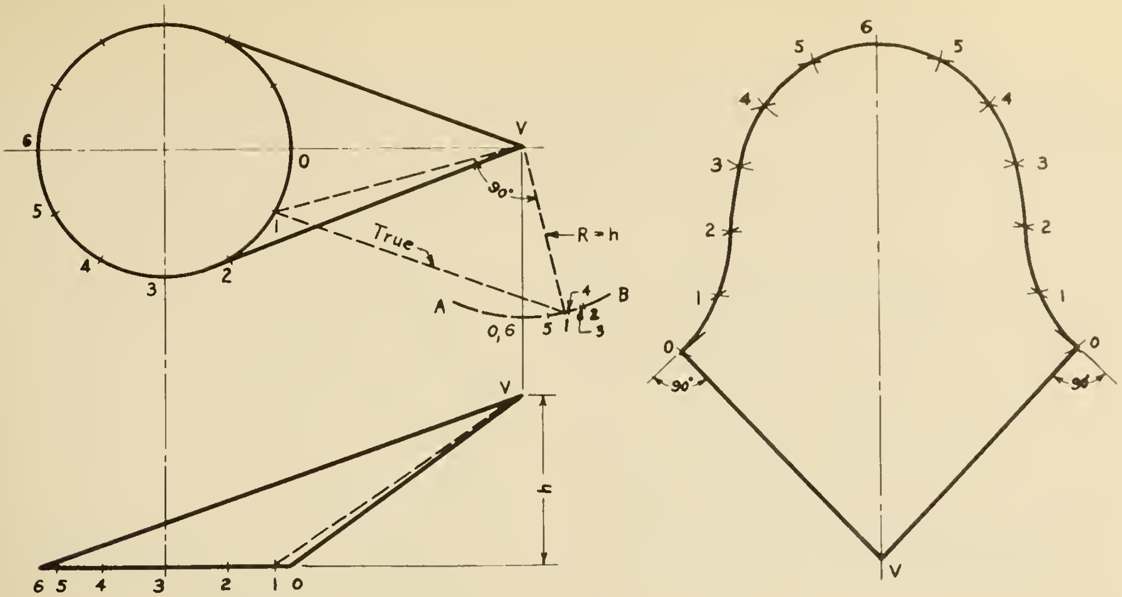


Figure 11-XII. Development of Oblique Cone

explained later). Other points are similarly located, i.e., by triangulation, and a smooth curve drawn through them. It should be noticed that the curve at point 0 is perpendicular to element V0. To construct the true length diagram: Draw arc AB with radius h. With V1 in the top view as one leg, construct the right angle triangle V-1-1', with 1' on the arc AB. Line 1-1' is the true length of element V1. Lengths of other elements are found similarly.

14-XII. Cylinder. A cylinder is a solid formed by a straight line generatrix which moves constantly parallel to a fixed straight line called the axis, and touches a fixed plane curve, called the directrix, not in the plane of either straight line. The bases are formed by two parallel planes. The elements of a cylinder are parallel and therefore meet at infinity. When the vertex of a cone is at an infinite distance from the base the elements become parallel and the cone becomes a cylinder.

For further terms and definitions, see Article 12-XII.

The development of the right circular cylinder is shown in Figure 12-XII. The circumference of the lower base, $2\pi R$, is laid out on the base line AB. For convenience, the lower base is divided into 12 equal parts. This operation can best be performed in the top view. Through these 12 points elements are drawn in the surface of the cylinder. The upper ends are numbered from 1 to 12 and are shown in all views. It can be seen from the drawing that the cylinder is cut by a plane perpendicular to a side plane and makes an angle of 30 degrees with a top plane and 60 degrees with a frontal plane. The base line AB is divided into 12 equal parts corresponding to the 12 divisions in the top view. Elements are erected at the division points perpendicular to AB. True lengths of the elements are obtained from either the front or the right side views and may be transferred to the development by the use of the dividers or may be drawn across from the front view as shown.

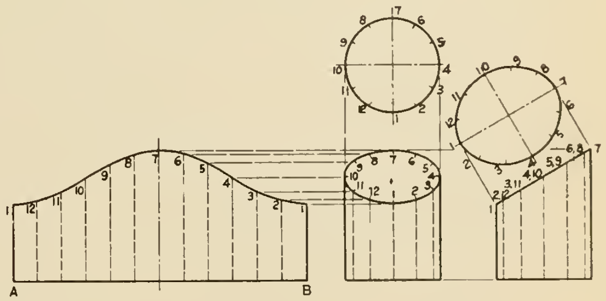


Figure 12-XII. Development of Right Circular Cylinder

15-XII. Oblique Cylinder. Elements of an oblique cylinder make equal, oblique angles with the bases. The altitude is the distance between parallel bases.

To Develop the Surface of an Oblique Cylinder. A half development of an oblique cylinder is shown in Figure 13-XII. Both bases are circular. The lower base lies in a horizontal plane. The upper base is perpendicular to a frontal plane and makes an angle of 60 degrees with a horizontal plane and 30 degrees with a side plane. To make the development: Divide the top view of the lower base into a convenient number of parts, say, 16 equal divisions. Draw the 16 elements in the front and top views. Construct the auxiliary view which will show a right section of the cylinder. Designate the ends of the elements in the lower base by lower-case alphabet; the upper ends by numerals. Draw in a base line x-y which is a plane perpendicular to the axis of the cylinder. In the development, erect 16 elements perpendicular to the base line x-y. The distances between the respective elements are obtained from the auxiliary view. From the front view, obtain the distances that the respective ends of the elements are from x-y by the use of the dividers, and lay off these distances on the respective elements in the development, measuring from x-y, as shown. That is, 1 is a distance p above x-y, a is a distance t below x-y, etc., in both the front view and the development.

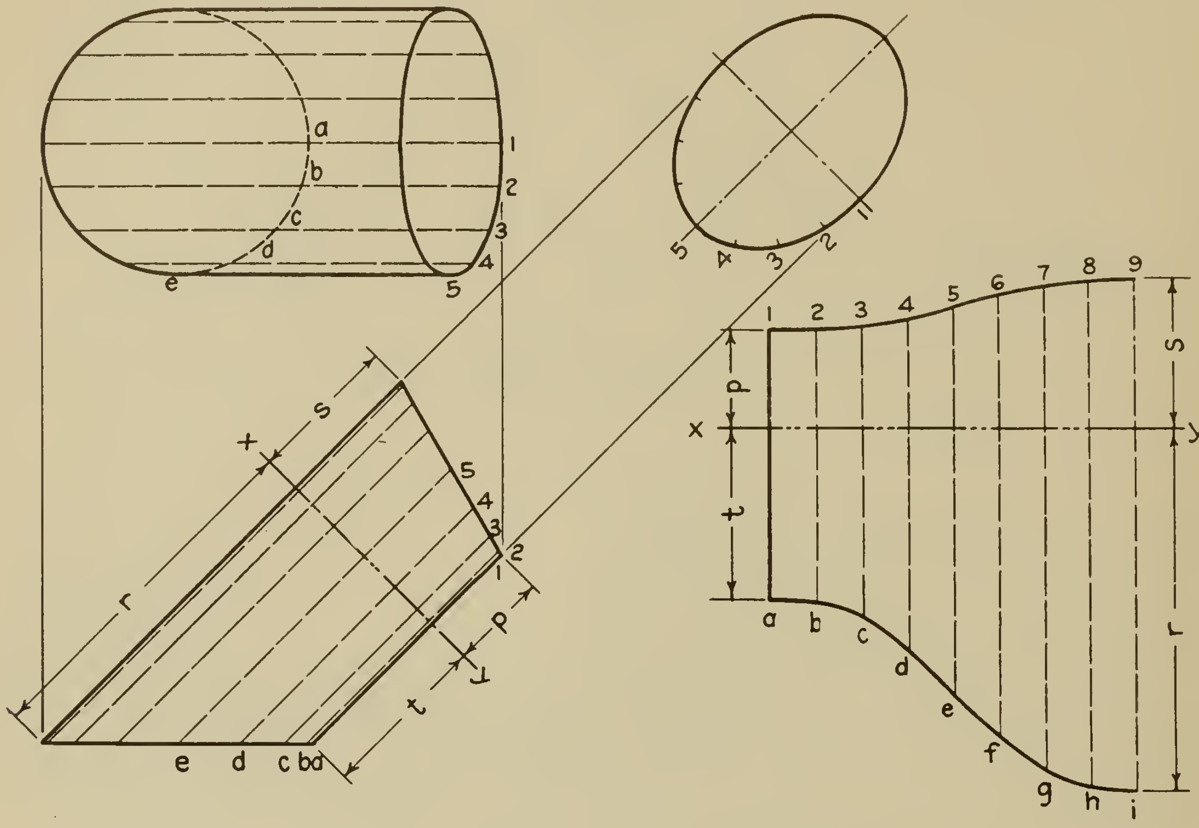


Figure 13-XII. Development of Oblique Cylinder

The method just used is very convenient in developing the surface of an oblique prism. See Figure 7-XII, Article 7-XII.

16-XII. Elbow. Figure 14-XII illustrates the half development of a four-piece pipe elbow, with equal diameters at either end and a least radius r. The angle xyz is 90 degrees. The two end sections extend a short distance past x-y and z-y in order to form sleeves by which connections with pipe joints are made. It should be noticed that the seams occur on the alternate shortest and longest elements so as to avoid having three seams meet at a point and to avoid waste in material. Only half developments of sections 1 and 2 are required.

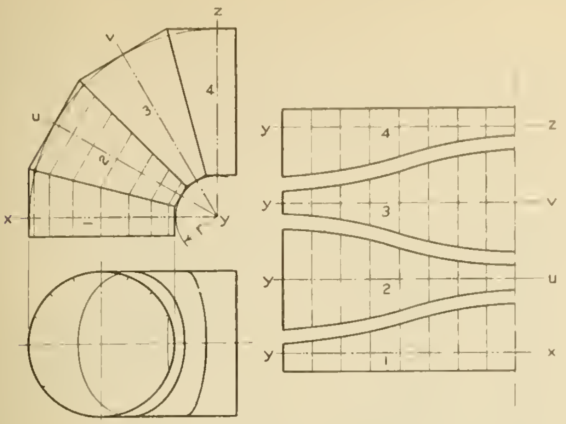


Figure 14-XII. Development of Four-piece Elbow

Angle xyz is divided into six equal parts. Sections 2 and 3 each contain two of these angles. The end sections contain one each. The number of equiangular divisions in an elbow is equal to two times the number of joints in the elbow, less two.

By increasing the number of pieces in an elbow, the amount of friction is reduced--thereby increasing the efficiency of the structure. The appearance is improved, but the cost of construction is increased. Increasing the least radius, r, will have a similar effect.

It should be noticed in Figure 14-XII that planes x-y, u-y, etc., are reference planes (cutting planes) perpendicular to a horizontal plane.

17-XII. Intersecting Cylinders. The line of intersection of two cylinders, A and B, and the development of cylinder A, are illustrated in Figure 15-XII. For a further discussion of the slicing plane method the reader is referred to Article 3-XII, Figure 4-XII.

Frontal slicing planes, W-W, X-X, Y-Y, etc., are used to cut slabs or sections from the object. Straight line elements are cut from both cylinders. Each pair of elements will intersect, and the point of intersection will lie on the line of intersection of the cylinders. That is, plane Y-Y will cut elements 1-2, 2-3, 4-5, and 5-6 as illustrated. Elements 1-2 and 2-3 will intersect at point 2; 4-5 and 5-6 will meet at point 5; and it will be noticed that points 2, 5, etc., lie on the line of intersection between the two cylinders. Plane W-W is tangent to cylinder A and will therefore locate only one point on the intersection, while the other planes will determine two points. Figure 15-XII.

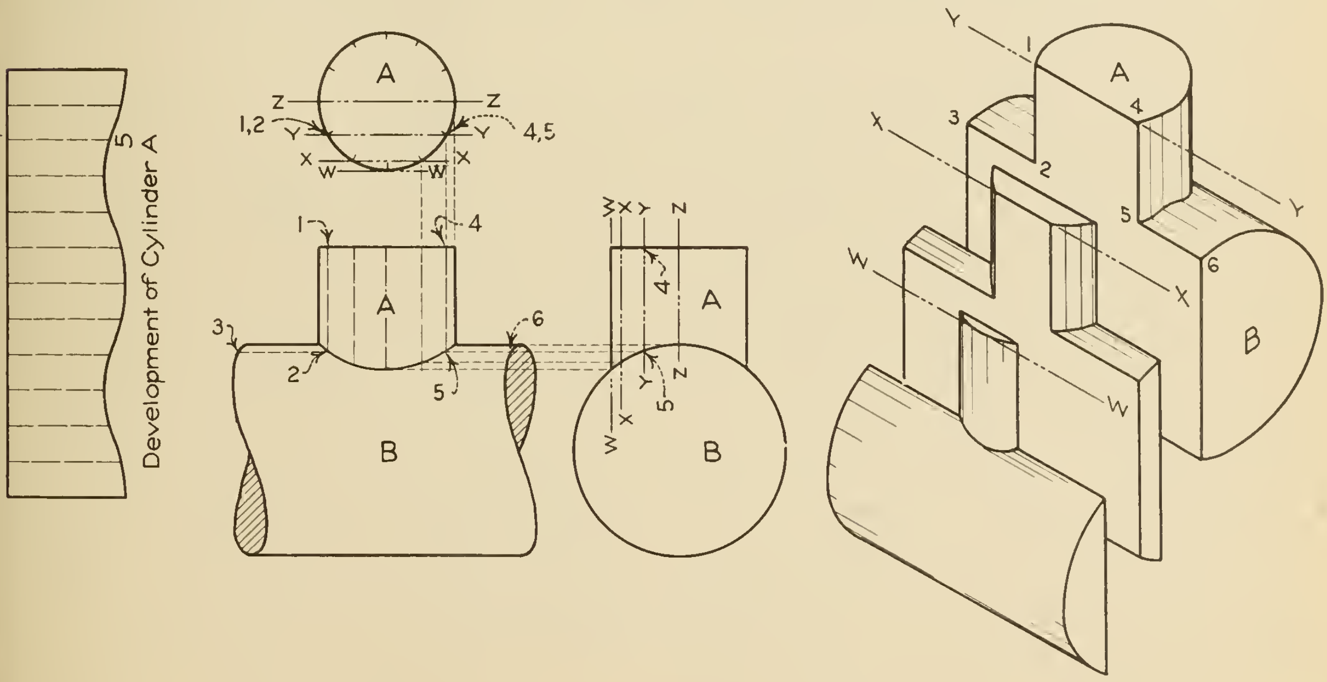


Figure 15-XII. Intersecting Cylinders

18-XII. Cone and Cylinder. Two methods of obtaining the line of intersection between a cone and a cylinder are illustrated in Figure 16-XII. Before making a study of the methods here illustrated, the reader should review thoroughly Articles 11-XII, 14-XII, and 16-XII. The slicing plane method is used in both drawings. In A, the plane is parallel to the base of the cone and cuts straight line elements from the cylinder, 2a and 6b, and a circular section from the cone, abc. The straight lines intersect the circle at points a and b, and these points lie on the line of intersection of the two objects. A sufficient number of planes are chosen to give an adequate number of points on the curve. The sharper the curve, the more points required.

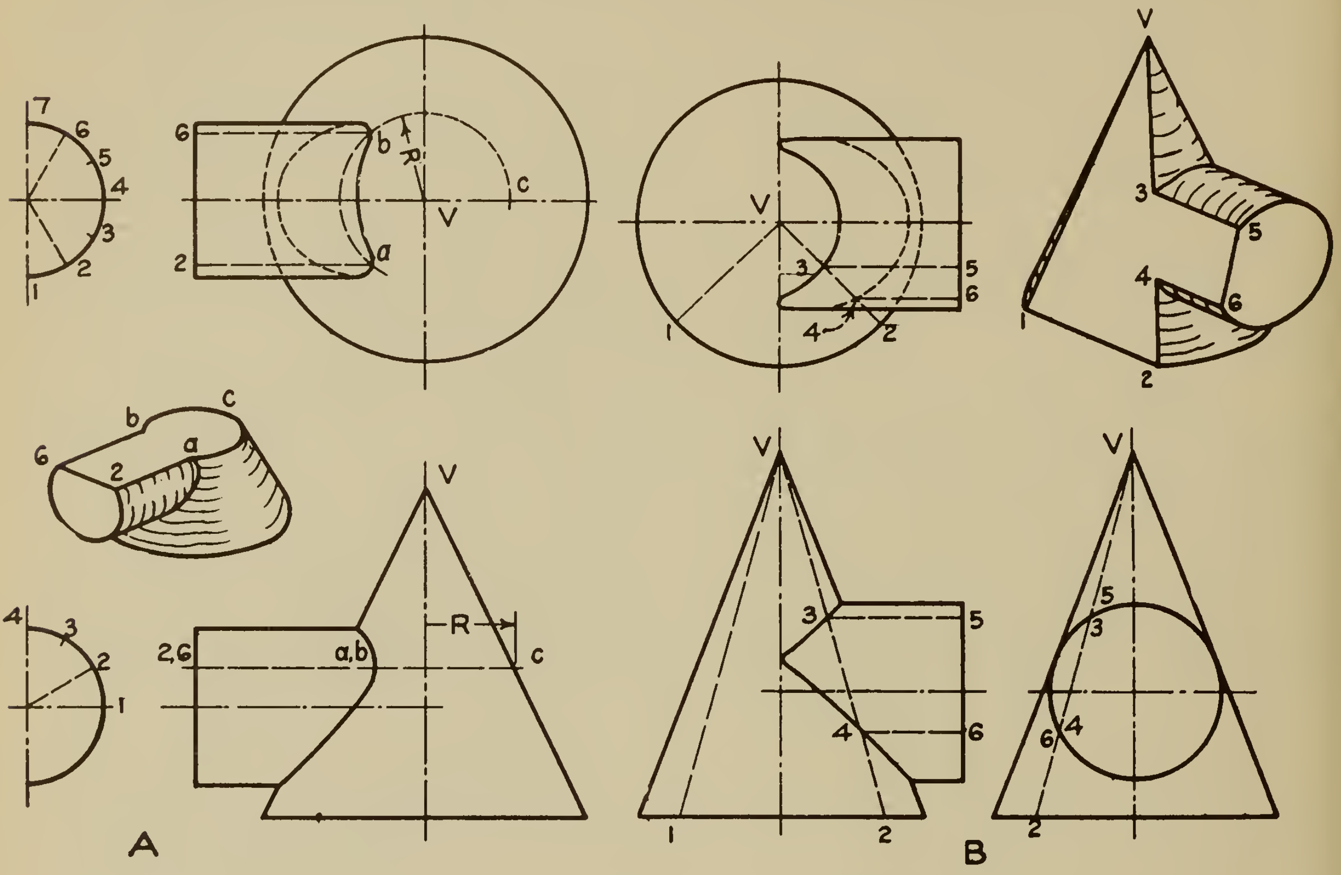


Figure 16-XII. Intersecting Cone and Cylinder

In drawing B, Figure 16-XII, all slicing planes pass through the vertex of the cone and are parallel to the axis of the cylinder. Straight lines are cut from both objects. Element V-1 obviously does not intersect the desired curve. Line V-2 is intersected by 3-5 and 4-6. Points 3 and 4 are on the line of intersection between the two objects.

The method of developing the surface of either of the intersecting objects is fully described in the articles referred to above.

19-XII. Cone and Prism. In determining the lines of intersection between a cone and a prism, Figure 17-XII, on the following page, horizontal slicing planes, X-X, Y-Y, and Z-Z, are used. Circles are cut from the cone, and regular hexagons are cut from the prism. These sections intersect on the desired curves, as illustrated. Planes X-X and Z-Z, define the limits of the curve. The circles cut by X-X and Z-Z will be the inscribed and circumscribed circles of the hexagonal section, respectively. The radius for circle X is shown in the front view. The six vertical planes of the prism cut hyperbolas from the cone. The curve cut by the frontal plane W is seen in true shape in the front view. The others are foreshortened.

The intersection problem just described is used to manufacture chamferred hexagonal bolt heads or nuts. In making the drawings, these curves are approximated with circular arcs. See Article 5-XIII.

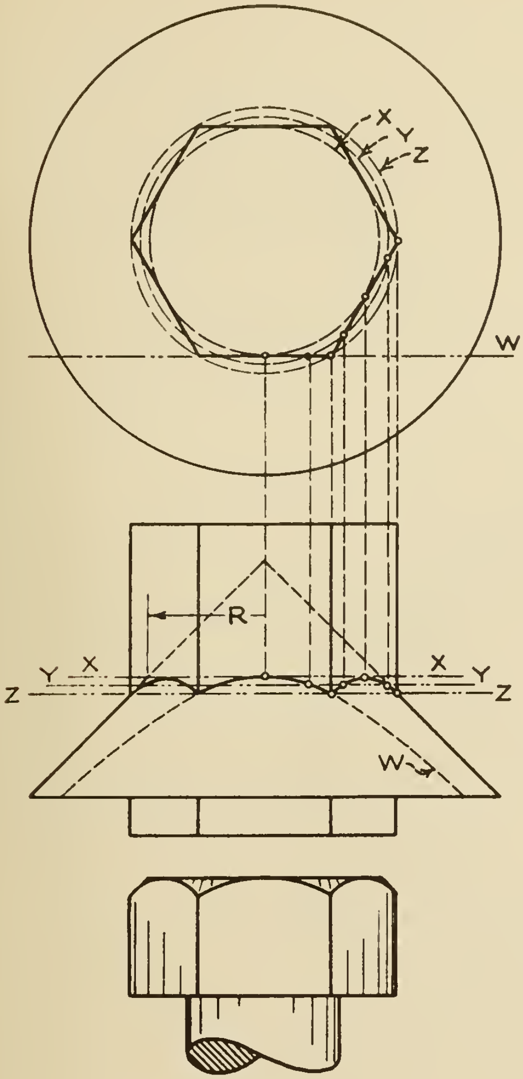


Figure 17-XII. Intersecting Cone and Prism

20-XII. Convolute. The convolute is a single-curved surface generated by a straight line which moves constantly tangent to a space curve. The surface is ruled and can be developed, since the elements are straight lines. Two consecutive elements will intersect, since the generatrix moves tangent to a space curve, but no three consecutive elements will intersect.

The only curved surfaces that may be developed accurately are the (1) cone, (2) cylinder, and (3) convolute.

21-XII. Helical Convolute. The helical convolute, Figure 18-XII on the following page, has for its directrix a helix. See also Figure 2-XII. The elements are tangent to a helix. A plane passed perpendicular to the axis of the cylinder will cut an involute of a circle, curve BC, from the convolute.

The front and top views and the development are shown. The generatrix is tangent to the curve at the upper end and has a definite length. The lower end of the generatrix traces another helix, larger in diameter than the directrix.

To Draw the Helical Convolute, Figure 18-XII. Given: Front and top views of a cylinder, radius r; helix CAK, lead 2 times MN; base LM equals half the circumference of cylinder; hypotenuse LN equals slope of half the helix, with slope angle φ; all elements tangent to helix CAK will have slope angle equal to φ. Required: Second helix through point B with lead equal to lead of helix CAK; a sufficient number of elements touching the two helical curves to define the convolute surface.

In the top view, draw element AB level (a frontal line), with a definite length, and tangent to the cylinder at point A. Draw AB in true length in the front view with slope equal to slope of LN. Through point B draw another helix with lead equal to lead of helix CAK. The two curves are the directrices, and AB is the generatrix of the convolute surface. To draw one complete turn of the convolute, divide the cylinder, radius r, into a convenient number of equal parts, starting at A. (Use the top view.) Draw elements at these division points tangent to the circle. Draw a second circle through point B, which is the top view of the helix drawn through B in the front view. Stop the tangent lines in the top view where they cross the outer circle. Locate these points in the front view on the outer helix. Locate the points of tangency in the front view on the inner helix. Connect respective points with straight lines which represent elements of the convolute surface. Only half of the elements for one complete turn are shown in Figure 18-XII (see next page).

A second method would be: Draw the elements in the top view as directed above. To obtain the front views of the various elements, see line JK, Figure 18-XII, draw an auxiliary elevation. The slope of JK, y:x, can be obtained from the triangle LMN. After the ends of the various elements have thus been located, draw a smooth curve through these various points. The curve just drawn will be the outer helix. The elements thus obtained will be the elements of the desired surface.

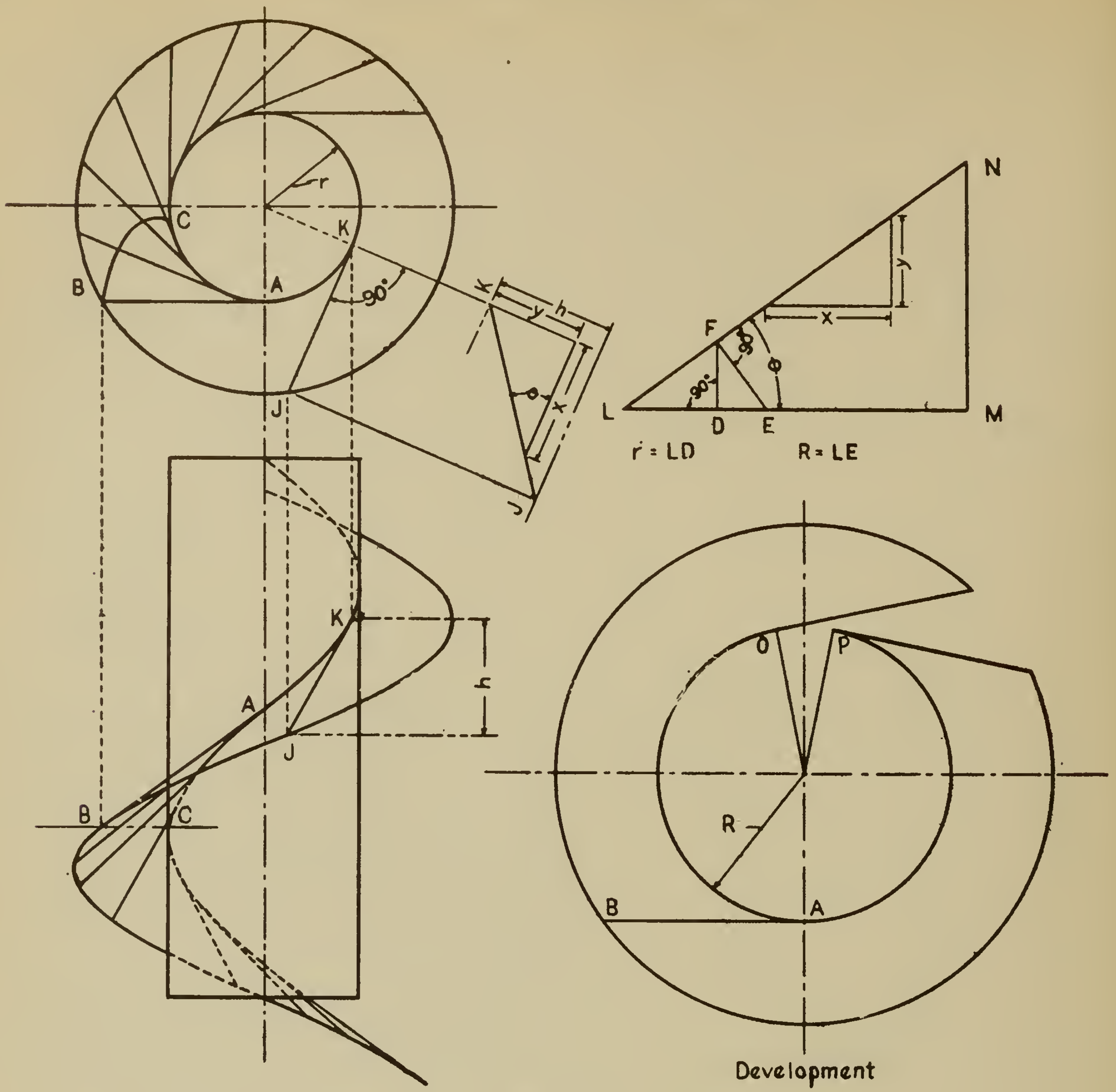


Figure 18-XII. Helical Convolute

22-XII. Convolute Development. The method of representing the surface of a convolute is described in Article 23-XII. To develop the surface of a convolute, Figure 18-XII, obtain the radius of curvature, R, as shown in triangle LMN. Draw LD equal to r, DF perpendicular to LM, and FE perpendicular to LN. The radius of curvature, R, is equal to LE. To make the development, draw a circle of radius R. At A draw a tangent to the circle equal in length to AB in the top view. Draw a concentric circle through point B. Lay off arcs AO and AP equal in length to the hypotenuse LN. Arc OAP is equal in length to a turn of the helical directrix drawn through points CAK. Draw tangents to the inner circle at points P and O. The arc drawn through B is equal in length to a turn of the outer helical directrix. Therefore, the development just drawn represents one turn, or flight of the convolute.

The surface of the blade of a screw conveyor is sometimes designed as a helical convolute. Such a surface, however, is not perpendicular to the shaft. The helicoid, a warped surface, is perpendicular to the shaft and is therefore preferable. The helical convolute is sometimes called the "developable helicoid." See Article 30-XII.

23-XII. Transition Section. A transition section is one which changes the cross section or geometrical shape, or changes the direction, of a pipe or conduit. In Figure 19-XII, a front and right side view is shown of a transition piece designed to connect sheet-metal piping with circular and elliptical sections. This surface is not a convolute. The circle and ellipse are horizontal and are therefore seen in true shapes in the top view. The triangulation method is used in making the half development. The development is symmetrical about a-1, a frontal line shown in true length in the front view, and is used as a base line. The frontal plane Y-Y is used as a reference plane. It is necessary to determine the distance that all points on the circle and on the ellipse are from Y-Y in order to determine the true lengths of the lines which form the triangles of the development. The diagram for determining the true lengths of lines is shown at the bottom of the drawing.

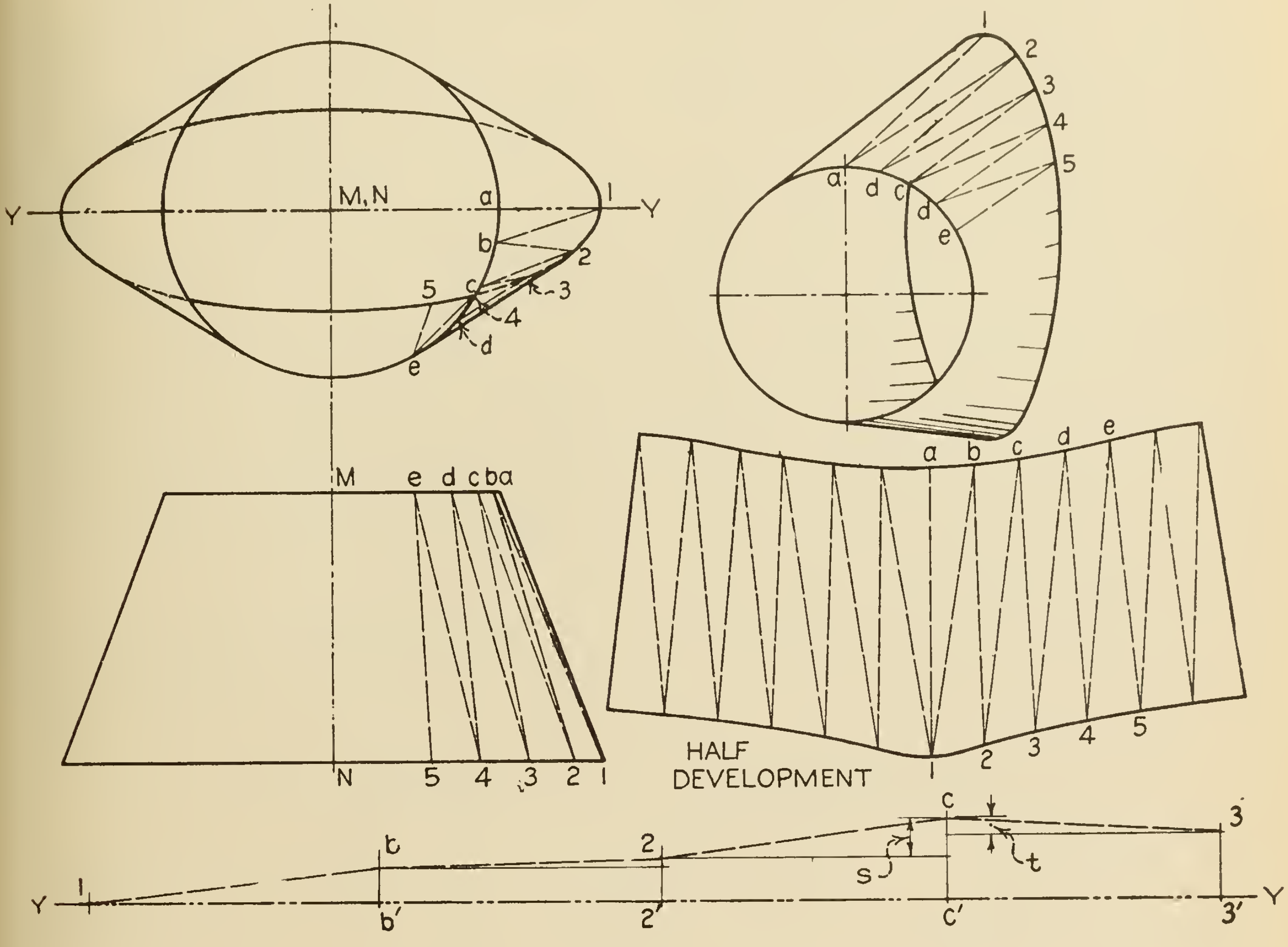


Figure 19-XII. Development of Transition Section

To make the development: Lay down the base line a-1 to be used as a center line in the half development. It is seen in true length in the front view. Find point b by locating intersecting arcs with radii ab and 1-b. Line ab is seen in true length on the horizontal circle in the top view. Obtain the front view of 1-b. Lay it off on the base line Y-Y in the true length diagram, thus locating b'. Erect a perpendicular at b'. Obtain the distance that b is from Y-Y in the top view and lay it off on the perpendicular just erected, thus locating b in the diagram. Connect 1-b, which is in true length. Point 2 is next located by sweeping arcs 1-2 and b-2. Distance 1-2 is seen in true length on the horizontal ellipse in the top view. Obtain the front view of b-2 and lay it off from b' on the base line Y-Y, thus locating 2'. Erect a perpendicular at 2'. Obtain the distance that 2 is from Y-Y in the top view and lay it off on the perpendicular, thus locating 2 in the diagram. Connect b-2, which is in true length. Other points are located similarly. It should be noticed in the diagram that coordinate s is the distance that c is in front of 2 and coordinate t is the distance that c is in front of 3.

It might help the beginner to turn the drawing so that the top view becomes the right side view. It can be seen that the true length method just used is based on the system of revolution previously presented and similar in construction to the true length diagram of Figure 7-XII.

24-XII. Cowl. A cowl is a hoodlike covering. A convolute surface is sometimes used to cover the motor of an automobile, cockpit of an airplane, pontoons of a seaplane, and the bow of a boat. It is used for similar transition surfaces when the curve directrices are parallel. Conical or cylindrical surfaces, however, are often used for this purpose, and a combination of these surfaces might be used. When such a covering or transition section is smooth (changes its direction gradually) it is said to be a "fair" surface. To determine whether or not a surface is fair, pass a plane parallel to the directrices cutting the surface. If the section thus obtained is a smooth curve, the surface is fair. This method can also be used to locate ribs or supports between the two end curves.

The method of designing a convolute surface for a boat is outlined in this Article 15-XVII (page 221).

The end curves for the convolute cowl of Figure 20-XII are frontal ellipses. The major axis AB is horizontal, while the major axis through CD is vertical. The skirts, i.e., the surfaces which lie below ABD, are warped surfaces and will be explained later.

A plane tangent to the convolute surface will be tangent along an element of the surface and will cut lines from the planes of the curves. These lines are tangent to the curves and parallel to each other.

To represent the convolute surface, Figure 20-XII: Choose point P on one of the ellipses. Draw a tangent to the ellipse at P. The tangent is the bisector of angle $F_2PO$ formed by the intersection of the focal radii. Draw a tangent to the second ellipse parallel to the first tangent. The point of tangency will be N. Line PN is an element of the convolute surface. Draw a sufficient number of these elements to define completely the required surface.

Frontal planes R and T are drawn, and their intersection with the surface is represented by the dotted curves in the front view. Since these curves are smooth, the surface is said to be fair. If intermediate supports (ribs) are desired, they should be shaped to the outlines of the dotted curves, and placed at the lines of intersections of planes R and T.

## Warped Surfaces

25-XII. The Warped Surface. The warped surface is a ruled surface in which no

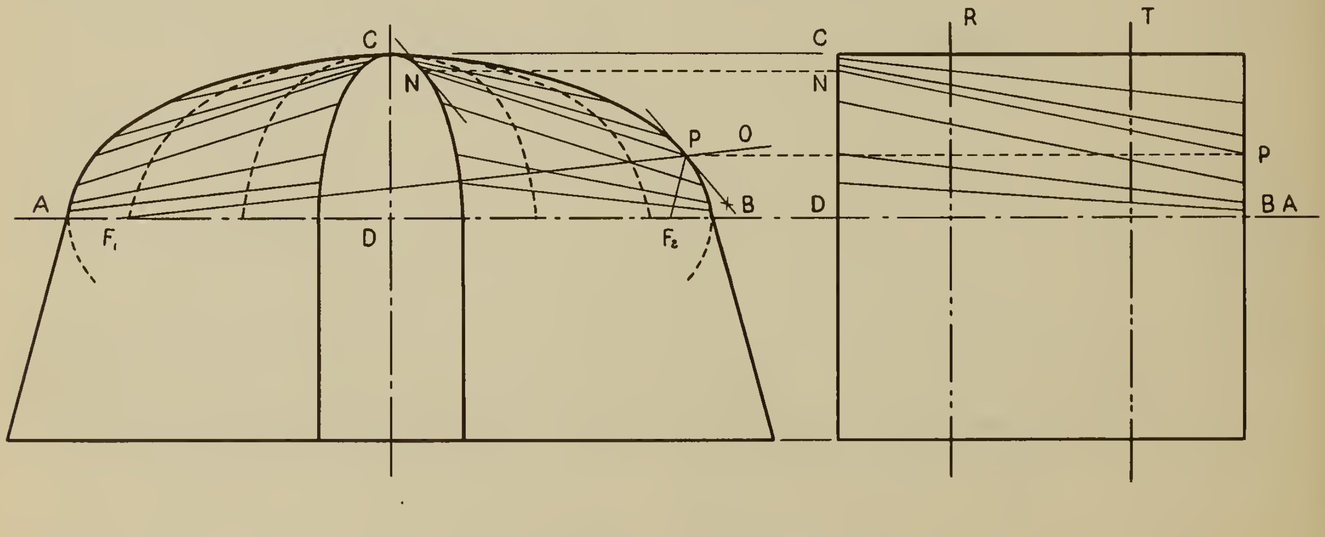


Figure 20-XII. Convolute Cowl

two consecutive elements lie in the same plane and therefore do not intersect. Two directrices and a director plane are usually used to govern the motion of the straight line generatrix. When three directrices are used, a director plane is not necessary. The generatrix constantly touches the directrices and remains parallel to the director plane. The directrices might be (1) straight lines, (2) curved lines, or (3) a straight line and a curved line.

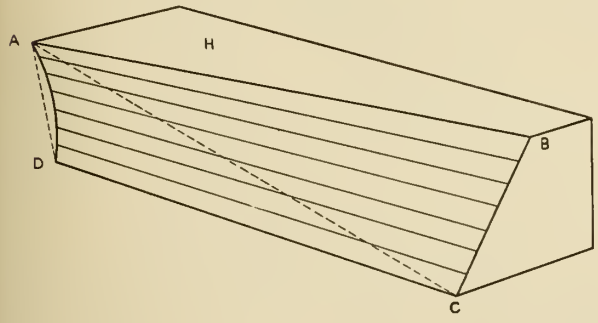


**Figure 21-XII. Warped Surface**

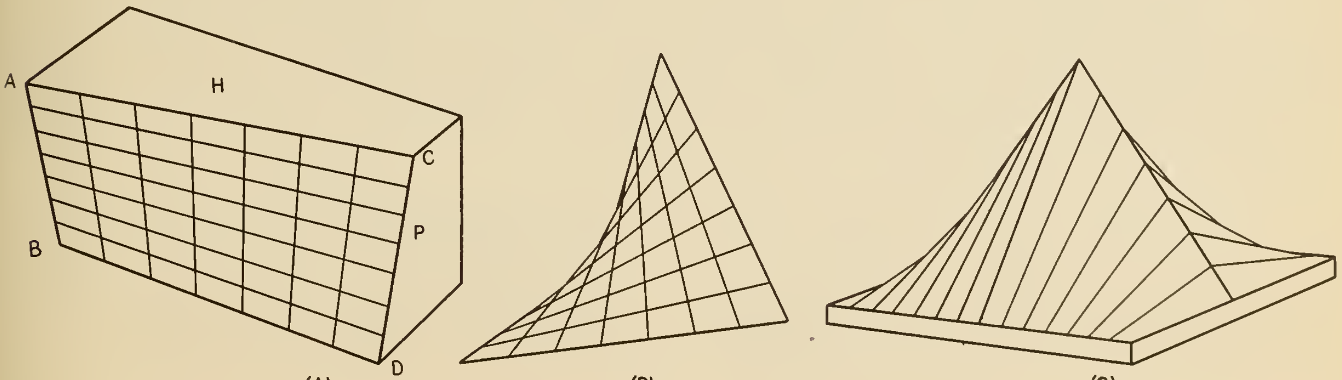
Figure 21-XII illustrates a warped surface with directrices AD and BC. Numerous elements are shown parallel to the horizontal director plane H. No two consecutive elements intersect; therefore, the development will have to be approximated. This approximation is done by triangulation. The surface ABCD is here divided into only two triangles, ABC and ADC, for illustrative purposes. In practice these triangles are made relatively small because smaller triangles will more nearly approximate the true surface. The straight lines AC and AD do not lie in the surface, but when the triangles are small they lie very near to the surface. Line AC would not lie in the surface even if the curved director AD were a straight line. If AC were an element the surface would be single curved. The development can now be approximated by triangulation, a method previously explained.

26-XII. Hyperbolic Paraboloid. The hyperbolic paraboloid is a warped surface generated by a straight line which moves parallel to a plane director and along two straight line directrices not in the same plane. The surface may be double-ruled, in which case the generatrix could move parallel to either the P plane or the H plane, as illustrated in Figure 22-XII (A). In either case the same surface is generated. Plane sections of the surface form straight lines, hyperbolas, or parabolas.

A double-ruled surface forms a relatively strong structure because it permits of more intricate bracing. The surface is often used for wing walls, abutments, certain roofs, bows of ships, portals, locomotive pilots, and other structures.

To Draw the Hyperbolic Paraboloid, Figure 22-XII (A): Given: directrices AC and BD and director plane P. Ends of the directrices lie in parallel planes. Required: a sufficient number of elements drawn in two or more principal views, parallel to plane P, to represent properly the surface. Divide AC into a convenient number of equal parts. Divide BD into the same number of equal parts. The straight lines connecting the division points will be the required elements. Directrices AB and CD and plane H could have been used to obtain the same results.

27-XII. Conoid. The conoid is a warped surface generated by a straight line which moves parallel to a plane director and along a straight line and a curved line



(A) (B) (C)

**Figure 22-XII. Hyperbolic Paraboloid**

directrices not in the same plane. The development is approximated by triangulation.

The conoid is used as a transition surface between a plane surface and a curved surface. Such a section is used to connect a circular metal flume with the trapezoidal earth section of an irrigation canal and is constructed of concrete. Other common examples are the transition surfaces connecting circular and rectangular cross sections and the connecting surface between the archway and a wall or ceiling.

Figure 23-XII represents a right conoid, and Figure 24-XII illustrates the oblique conoid. The surfaces cannot be double ruled. Plane sections perpendicular to the axes are ellipses.

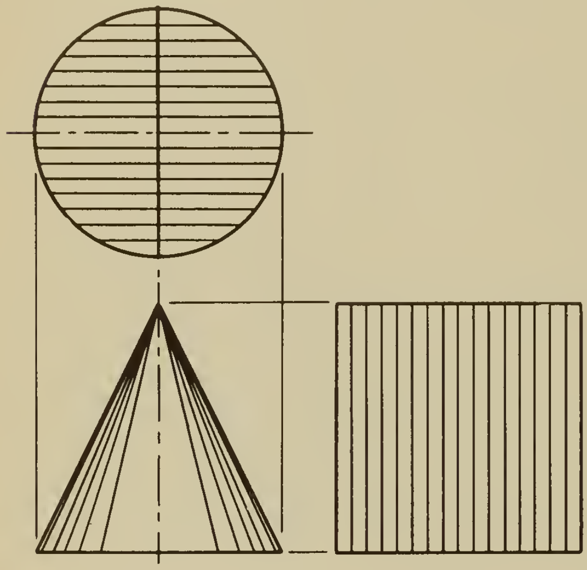


**Figure 23-XII. Right Conoid**

The elements are here parallel to a frontal plane. In the right conoid they are equally spaced in the top and side views. To draw the elements of an oblique conoid, the base is divided into equal parts, and straight lines are drawn through these points parallel to the plane director.

28-XII. Cylindroid. The cylindroid is a warped surface generated by a straight line which moves parallel to a plane director and along two curved line directrices not in the same plane. See Figure 25-XII. The development is approximated by triangulation. The cylindroid is used as a connecting surface between two curves in non-parallel planes. Such a condition is met with in the construction of skew arches and similar structures.

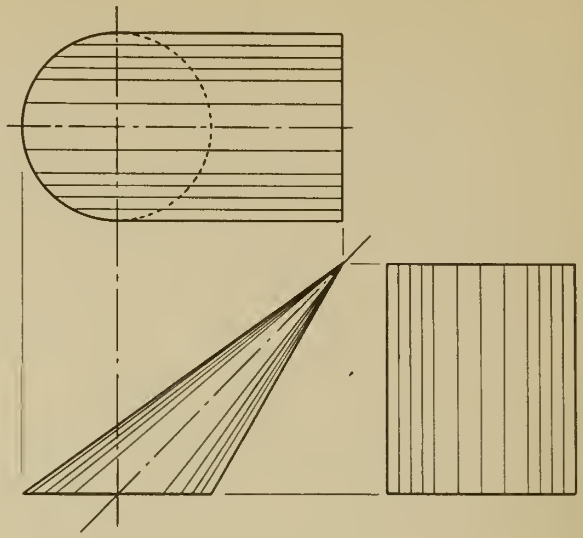


**Figure 24-XII. Oblique Conoid**

The plane director in this case is horizontal. Curve director A in the illustration is divided into equal parts in the front view. The elements are drawn as level lines in the front and are projected from there to the top view.

29-XII. Streamline Surfaces. It is often difficult to differentiate between the hyperbolic paraboloid, conoid, and cylindroid.

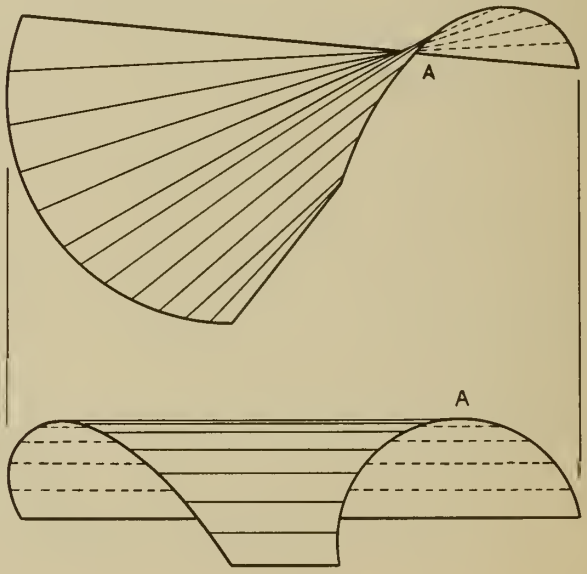


**Figure 25-XII. Cylindroid**

They are similar in that each is a warped surface with a plane director and a straight line generatrix. Their differences are (1) the hyperbolic paraboloid has two straight line directrices, (2) the conoid has a straight line and a curve line directrices, and (3) the cylindroid has two curve line directrices.

Streamlining usually conforms to one of these three surfaces or some combination of them. Examples of this type of design are found in boat, airplane, and automobile construction.

30-XII. Helicoid. The helicoid is a warped surface generated by a straight line which intersects the axis at a constant angle while moving along the axis, and while intersecting a helical curve. If the generatrix makes an angle of 90° with the axis, a right helicoid is formed. When the angle between the generatrix and the axis is oblique, an oblique helicoid is obtained. See Figure 26-XII. Instead of specifying a right or an oblique angle which the generatrix shall make with the axis, a plane surface or a conical surface, respectively, may be used as director surfaces.

The helicoid is not double-ruled. The

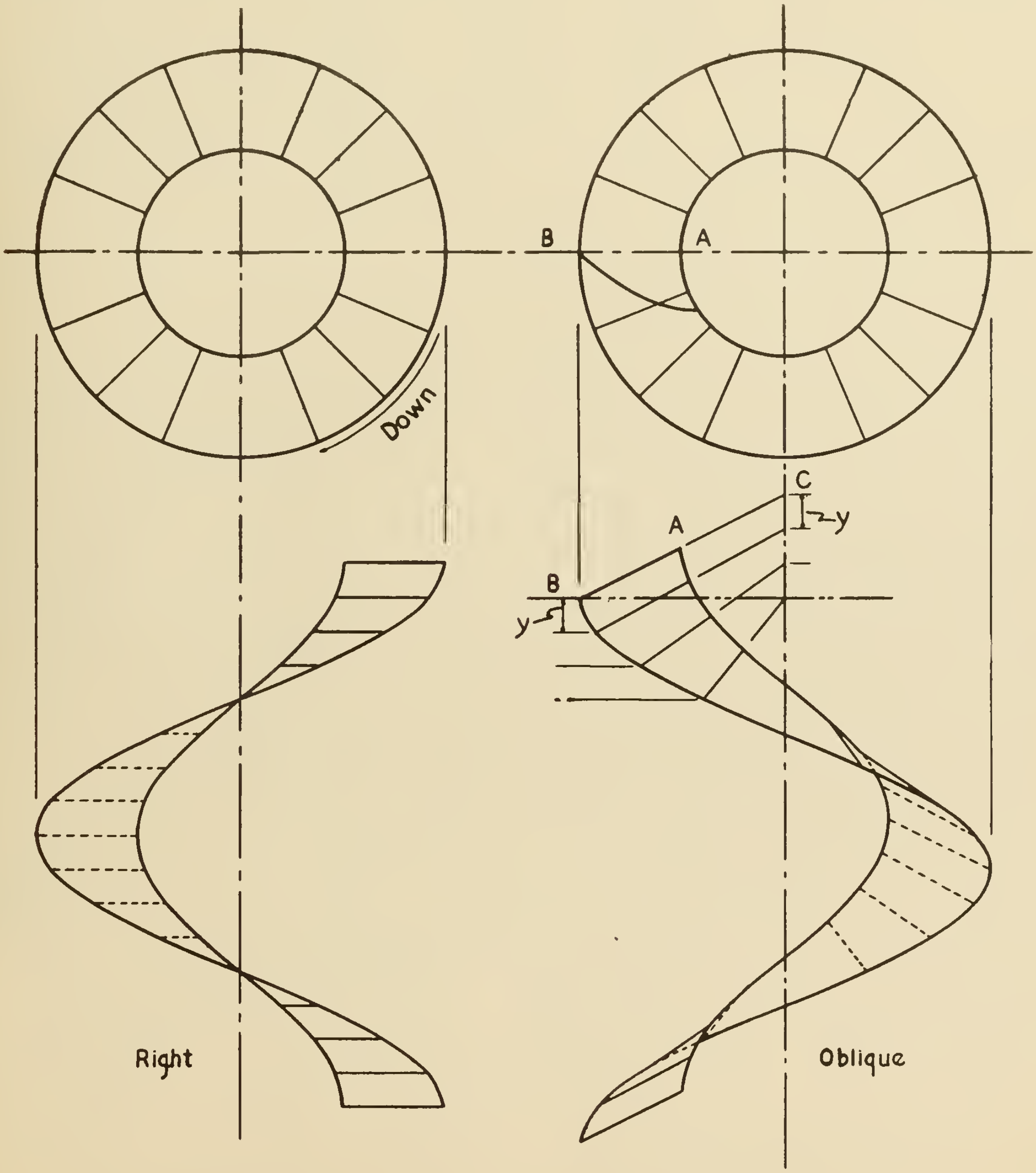


Figure 26-XII. Helicoids

development is approximated by triangulation. Attention is here called to the convolute.

The helicoidal surface has a wide application. It is the wearing surface of screw threads, Figure 29-XII; of helical springs of square cross section; of helical stairways, ramps, and screw conveyors, Figure 27-XII; of pipe bends, Figure 28-XII; of screw propellers; helical cones, helical chutes, and many other surfaces found in engineering structures.

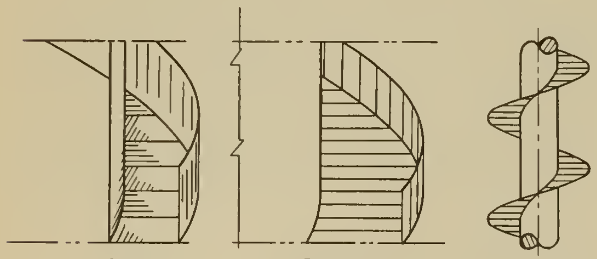

Stair (A)
Ramp (B)
Conveyor (C)

Figure 27-XII. Some Examples of Helicoidal Surfaces

To Draw a Right Helicoid: One term of a right helicoid is shown in Figure 26-XII. To represent the surface by drawing a sufficient number of elements, divide the major and minor circles in the top view into the same number of equal parts. Connect corresponding points. Lay off on the axis in the front view the lead for the two helices. The two leads are identical in position and length. Measuring parallel to the axis, divide the lead into the same number of equal parts as used in the top view. Through these points draw the elements in the front view perpendicular to the axis. Project the ends of the elements from the top view to the front views. The curves connecting the ends of the elements in the front view are helices.

To Draw an Oblique Helicoid: One turn of a left-hand helicoid is shown in Figure 26-XII. To represent the surface by drawing a sufficient number of elements, divide the major and minor circles in the top view into the same number of equal parts. Connect corresponding points. Draw the normal element AB and extend it to meet the axis at C. The slope of AB is equal to the slope of an element of the cone on which the helix is drawn. Draw the lower curve through point B. From point C lay off a distance equal to the lead and divide this distance into the same number of divisions made of the circles in the top view. One of these divisions is a distance y. Below B, draw lines perpendicular to the axis and y distance apart. Extend these lines to cut the helix. Connect corresponding points on the curve and on the axis. From the top view, project the ends of the elements which lie on the small circle to the elements of the front view. The curve drawn through these points will be the second helix.

A plane passed perpendicular to the axis (see point B) will cut a spiral of Archimedes from the oblique helicoid.

31-XII. Pipe Ells. Figure 28-XII illustrates a pipe elbow or transition piece with uniform, rectangular cross section. The ell makes a 90° turn and in so doing, rises at a uniform rate. The intersections form four helical curves. The two vertical faces are cylindrical surfaces, while the upper and lower surfaces are right helicoids. The elements are drawn as indicated, and the helical developments should be approximated by triangulation. They are similar. A development should be made of each of the cylindrical surfaces.

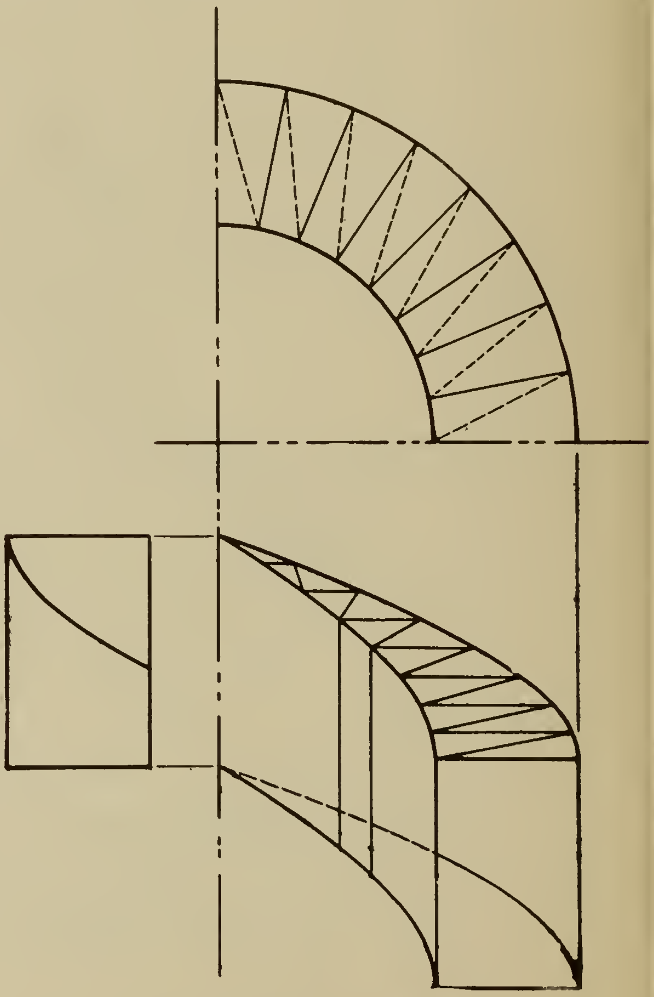


Figure 28-XII. Pipe Ell

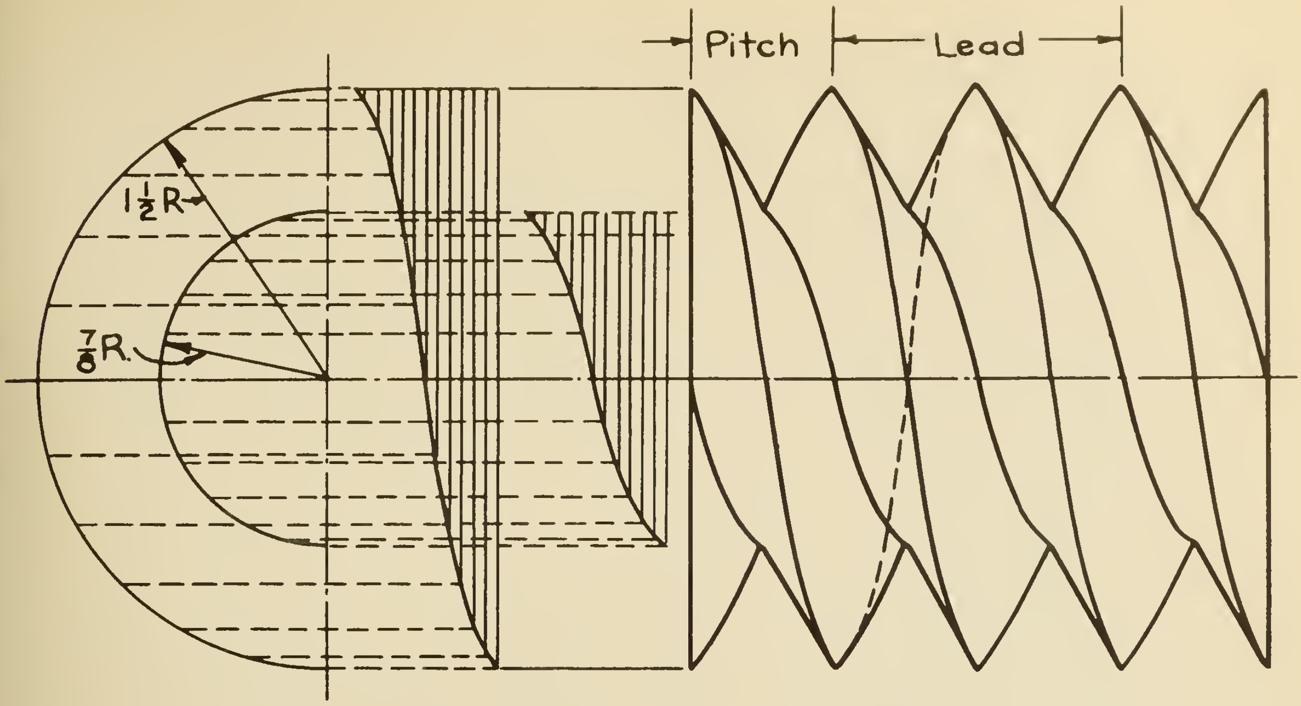


Figure 29-XII. Double, V-sharp Thread

32-XII. Screw Threads and Springs. The wearing surfaces of square screw threads and springs of rectangular cross section (wound on a cylinder) are right helicoids. The wearing surfaces of the various types of V-shaped threads are oblique helicoids, as illustrated in Figure 29-XII. Elements have been omitted in this drawing, but the helicoidal or wearing surface could well be defined by the use of elements. Numerous examples of both types of surfaces can be found in the chapter on fasteners.

33-XII. Surfaces of Revolution. Surfaces of revolution are generated by revolving a generatrix about a straight line as an axis. Some common ruled surfaces of revolution are the cylinder, cone, and hyperboloid of revolution. Numerous double-curved surfaces of revolution are found. Some of the more common examples are the sphere, ellipsoid, and torus. Double-curved surfaces are treated in later articles in this chapter.

34-XII. Hyperboloid of Revolution. The hyperboloid of revolution is a warped surface generated by a straight line when revolved about a straight line axis, provided the generatrix and the axis are neither parallel nor intersecting. Straight line circular and hyperbolic sections may be cut from the hyperboloid of revolution. When the cutting plane is perpendicular to the axis a circle is obtained. The smallest possible circle which can be cut is called the gore circle. The radius of the gore circle is the shortest distance between the axis and the generatrix.

The surface is double-ruled. The development is approximated by triangulation.

Light, slender structures can be made relatively rigid when composed of straight members forming a double-ruled hyperboloid of revolution. The positions of the members are indicated by the various elements shown in Figure 30-XII on the following page. Some common examples are the various types of towers, reed furniture, and baskets. Occasionally skew gears are cut on this type of surface.

To Draw the Hyperboloid of Revolution: Obtain a view looking in the direction of the axis. Draw the gore circle and two end circles. The top view of Figure 30-XII is such a view. The two end circles are C and E. The gore circle is D (see front view). Draw a convenient number of elements in the top view tangent to the gore circle, as element AB. A lies in one end circle, B in the other end circle.

## Double-curved Surfaces

35-XII. The Double-curved Surface. When classifying surfaces, we say that the

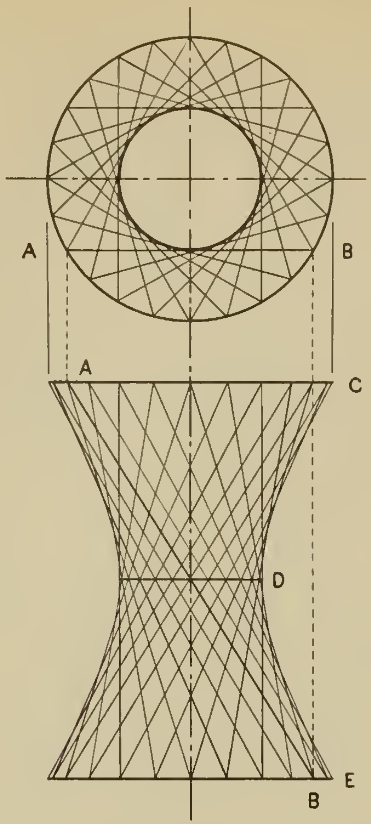


Figure 30-XII. Hyperboloid of Revolution

two main divisions are (1) ruled, and (2) double-curved. The former has straight line elements, while the elements of the double-curved surface are curved lines. An accepted definition is: A double-curved surface is one which is curved in every direction. Many double-curved surfaces are surfaces of revolution.

Surfaces of revolution are easily made, by turning in a lathe or on a potter's wheel, cast from turned patterns, formed by certain rolling processes, or shaped with dies. There are numerous examples of the double-curved surfaces. Among the more common examples are the sphere, ellipsoid, torus, serpentine, and numerous irregular objects used for decorative purposes, ornaments, portals, archways, pottery, etc.

The double-curved surfaces are represented (as are other surfaces) by locating certain characteristic lines in the surface. The development is approximated by enclosing the object in sections of cones or cylinders. These single-curved surfaces can then be developed. A map, which is a projection (on a horizontal plane) of the earth's surface is such a development.

36-XII. Sphere. A sphere is a double-curved surface generated by a circle revolved about a diameter as an axis. Any view or projection of a sphere is a circle regardless of the theoretical type of drawing used. Any plane section of a sphere is a circle. If the cutting plane passes through the center of the sphere, the section is a great circle of the sphere. For a given surface, the sphere has a greater volume than any other type of structure. The stress in the material of a spherical structure, when subjected to pressure, is uniform throughout the structure.

As previously pointed out, a map is a development of the earth's surface. The earth is considered an oblate spheroid. Balls in a bearing are spheres. The ball is first forged or turned to approximately the

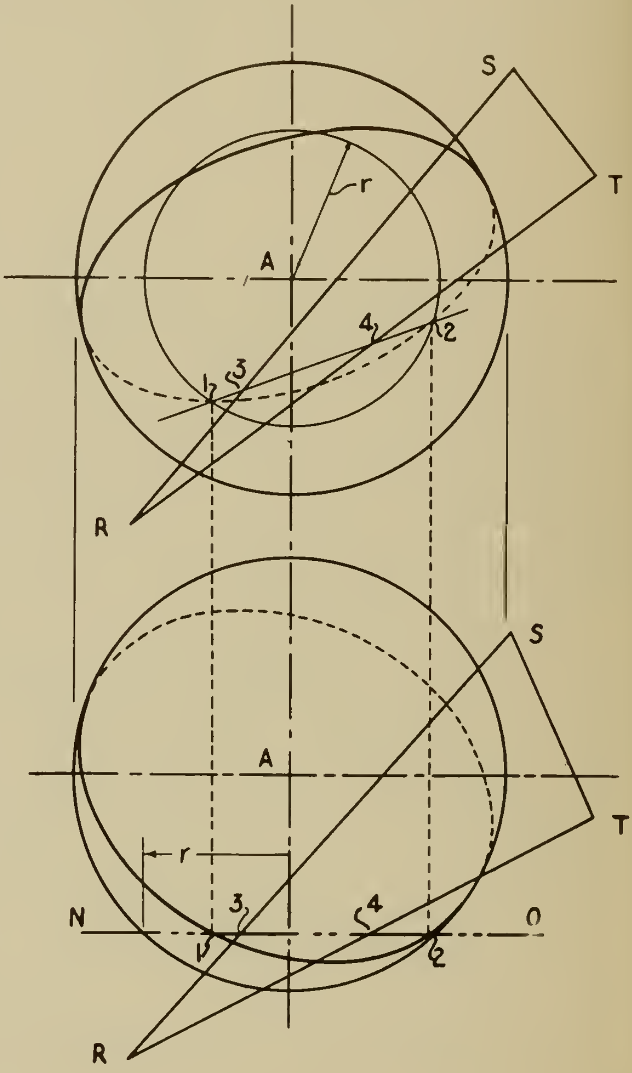


Figure 31-XII. Intersecting Sphere and Plane

required diameter and then, after hardening, is ground and lapped between parallel disks to the desired size. The tolerance is often specified as one ten-thousandth of an inch. Balls are used for various other purposes. Hemispheres are used for domes of structures and for bottoms of water tanks. Spherical tanks are used to store gas under high pressure. Numerous other examples of lesser importance are common.

To Find the Intersection Between a Sphere and an Oblique Plane: Use horizontal, frontal, or profile planes to slice the sphere A and oblique plane RST, Figure 31-XII. In this case horizontal planes were chosen and NO is one of several planes needed. Obtain radius r from the front view and draw the circle in the top view which was sliced from the sphere. Locate 3-4, the line of intersection between planes NO and RST. Locate 1-2, points of intersection between 3-4 and the circle. Points 1 and 2 lie on the desired intersection between RST and the sphere. Repeat the operation until a sufficient number of points have been located. Then draw a smooth curve through the points.

To Find the Intersection between Two Spheres: The principle of Figure 31-XII is applied, as described above. Draw a series of horizontal, frontal, or profile slicing planes. Circles will be cut from both spheres. These circles will cross at points which lie on the desired line of intersection. Draw the curve.

To Develop the Sphere: Two methods in common use when approximating the development of the sphere are:

1. When the meridian method is used, Figure 32-XII, the sphere is enclosed in short sections of a cylinder, drawn tangent to the sphere. Cylinder ABCD is such a section. Lines are drawn through points A, B, C, and D connecting the two poles N and S. The remainder of the cylinder is discarded. The discarded portions contain the greatest amount of error. The developed meridian sections are usually stretched to a spherical shape before they are put into place. One-sixteenth of the development is shown.

2. When the zone method is used, Figure 33-XII, the sphere is enclosed in the short sections of cones, drawn tangent to the sphere. Cones A, B, C, and D are used to enclose the upper half of the sphere. The

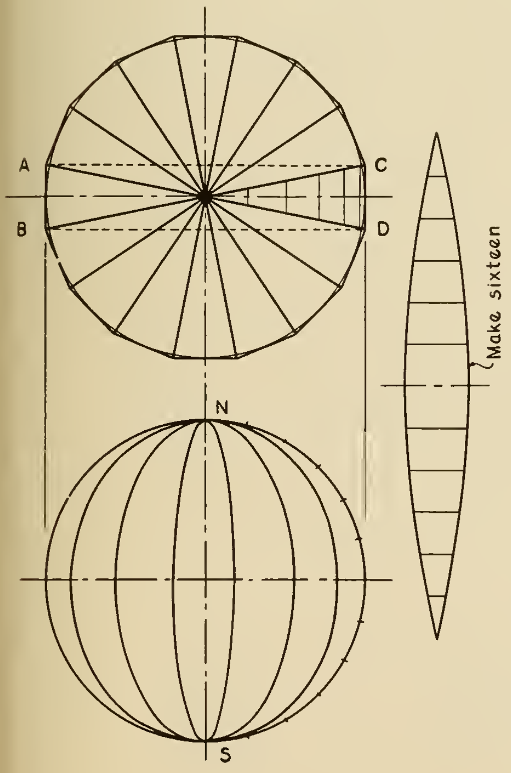


Figure 32-XII. Sphere Developed by Meridians

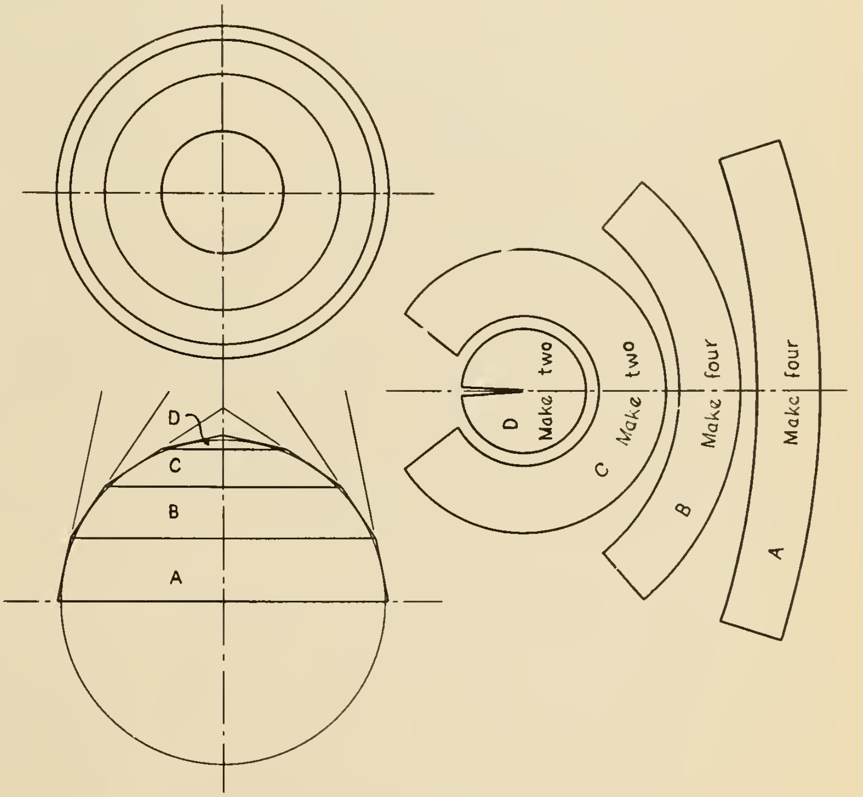


Figure 33-XII. Sphere Development by Zones

required development is shown to the right.

To Find the Intersection between a Sphere and a Prism: Frontal slicing planes were used in determining the lines of intersection between a sphere and prism, Figure 34-XII. Either horizontal or frontal planes could have been used. The curves of intersection are circular arcs. The arc cut by plane Z-Z shows in true shape in the front view. The top of the finished object, an arc of a great circle of the sphere, is circular. The other curves are distorted.

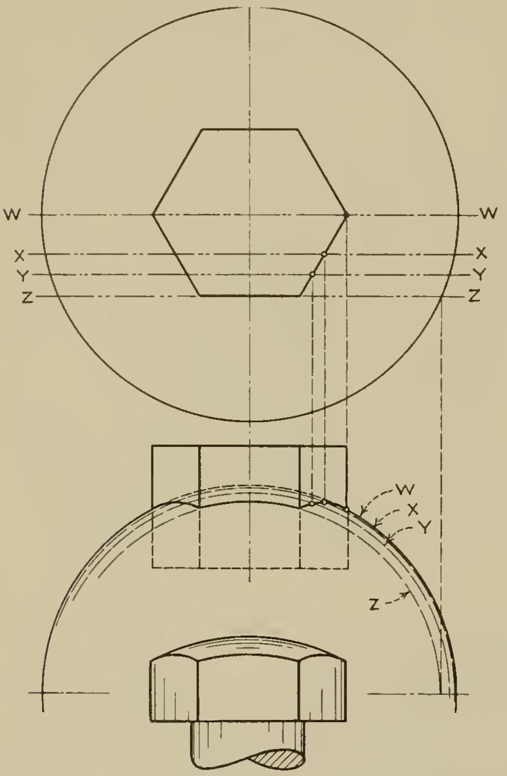


Figure 34-XII. Intersecting Sphere and Prism

The method just described is used in manufacturing rounded hexagonal bolt heads or nuts. These curves are approximated in drawings with circular arcs. See Article 19-XII.

37-XII. Ellipsoid. The ellipsoid is a double-curved surface generated by revolving an ellipse about one of its axes, Figure 35-XII. When the minor axis is used as the axis of revolution, an oblate ellipsoid is obtained. A prolate ellipsoid is obtained by revolving the generatrix about its major axis.

These surfaces are used for ornamental designs, large tank construction, approximating spheroids, and for domes of buildings.

The development may be approximated by the meridian method or the zone method, as outlined in Article 36-XII.

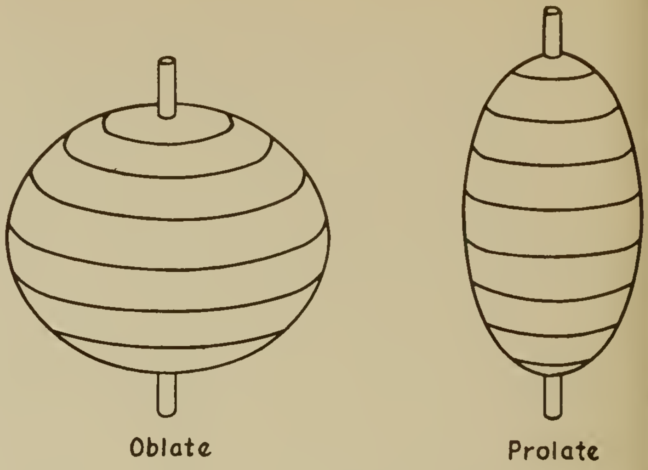


Figure 35-XII. Ellipsoids

38-XII. Annular Torus. An annular torus is generated by revolving a circle about an axis which lies outside the circle, but in the plane of the circle.

The torus is the surface made from cylindrical material (round stock) when the center line of the stock is twisted out of a straight line, such as rings, tubes, pipe bends, etc. It is the surface of fillets and rounds which have been turned down in a lathe. Example: the stub end of an old-style connecting rod.

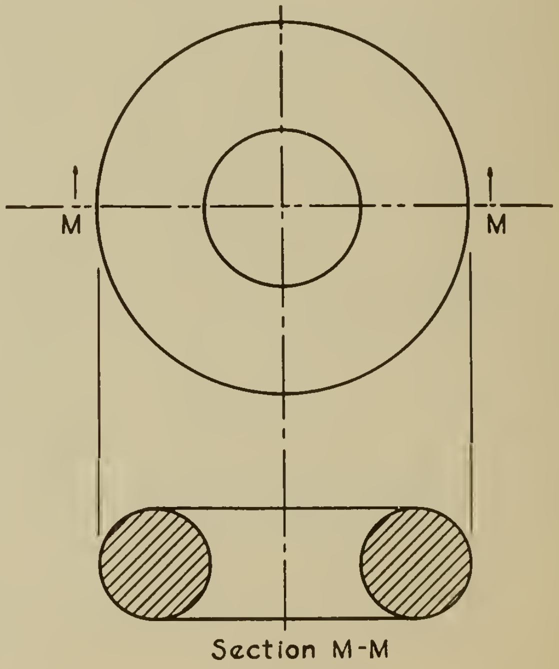


Figure 36-XII. Annular Torus

The intersection between the torus and another surface may be found by passing cutting planes perpendicular to or through the axis of revolution. In either case, circles will be cut from the torus. The development is approximated by enclosing the torus in short sections of a cylinder, Article 16-XII, or by the zone method, Article 36-XII.

39-XII. Serpentine. The serpentine is a double-curved surface generated by a sphere which moves so that its center touches a helix, Figure 37-XII (C).

The serpentine is the surface of helical springs made of round stock. Drawing (C), Figure 37-XII is the true representation of a cylindrical helical spring. Drawings (A) and (B) are the conventional representations of the two types of springs, i.e., conical and cylindrical. The development is approximated by enclosing the surface in short sections of a cylinder. See Article 36-XII.

## EXERCISES

40-XII. The problems of this chapter are intended to fit in a space 8" x 11". It is recommended that the instructor assign at least one model to be constructed from a development that has been made. Tabs and fasteners should be provided for the models. Intersecting objects should be considered as one solid piece. Full developments (including the bases) should be made, unless instructions to the contrary are given. When objects are truncated, the cutaway portion is discarded in the final views. Dimension all drawings.

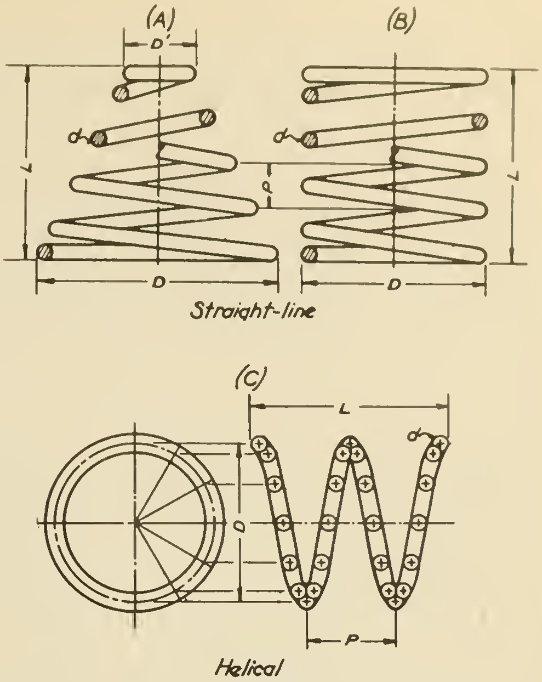


Figure 37-XII. Spring Representations

### Group 1-XII. Truncated Solids

1 to 5 inclusive, Figure 38-XII. Cut the object at the mid point of the axis with a plane making an angle of 45 degrees with a side or top plane, perpendicular to a frontal plane, and sloping down and to the right. Add a side view of the truncated object and make normal view drawings of all lateral surfaces, including the bases.

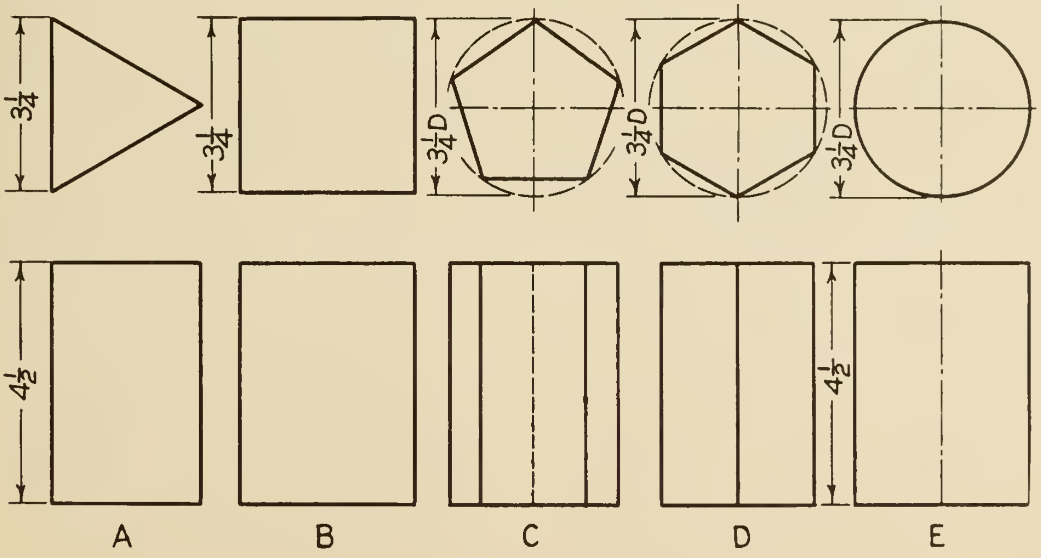


Figure 38-XII. Right Prisms and Cylinder to be Truncated

6 to 8 inclusive, Figure 39-XII. Cut the object at the mid point of the axis, with a plane located as follows: (A) making an angle of 45 degrees with a side or top plane, perpendicular to a frontal plane, and sloping down and to the right; (B) same as (A) but sloping down and to the left, (C) making an angle of 45 degrees with a frontal or top plane, perpendicular to a side plane, and sloping down and to the right. Add a side view of the truncated object and make normal view drawings of all lateral surfaces, including the bases.

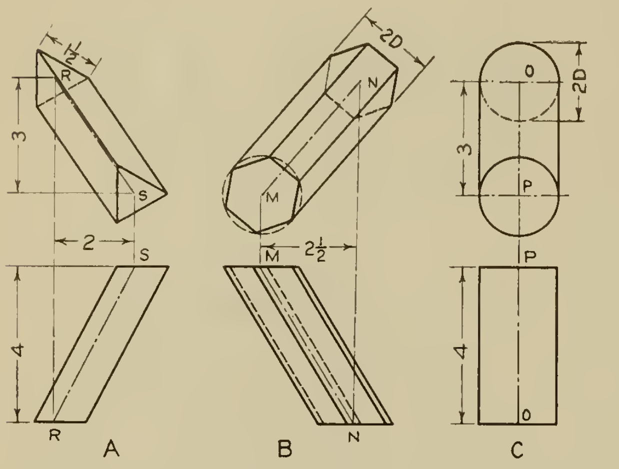


Figure 39-XII. Oblique Prisms and Cylinder to be Truncated

9 to 12 inclusive, Figure 40-XII. Cut the object as directed in problems 1 to 5. Add a side view of the truncated object and make normal view drawings of all lateral surfaces, including the bases.

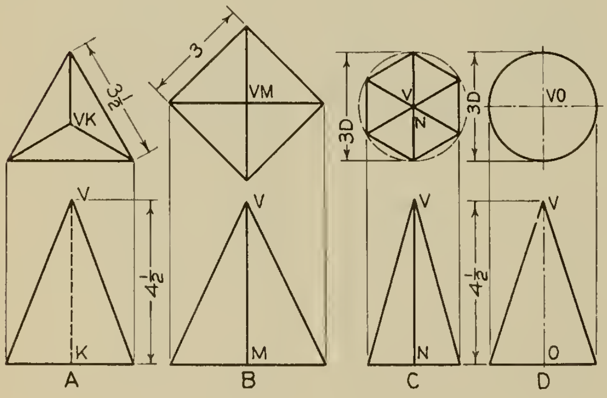


Figure 40-XII. Right Pyramids and Cone to be Truncated

13 to 15 inclusive, Figure 41-XII. Cut the object at the mid point of the axis with a plane located as follows: (A) making an angle of 45 degrees with a side or top plane, perpendicular to a frontal plane, and sloping down and to the right; (B) same as (A) but sloping down and to the left; (C) making an angle of 45 degrees with a frontal or top plane, perpendicular to a side plane, and sloping down to the right. Add a side view of the truncated object and make normal view drawings of all lateral surfaces, including the bases.

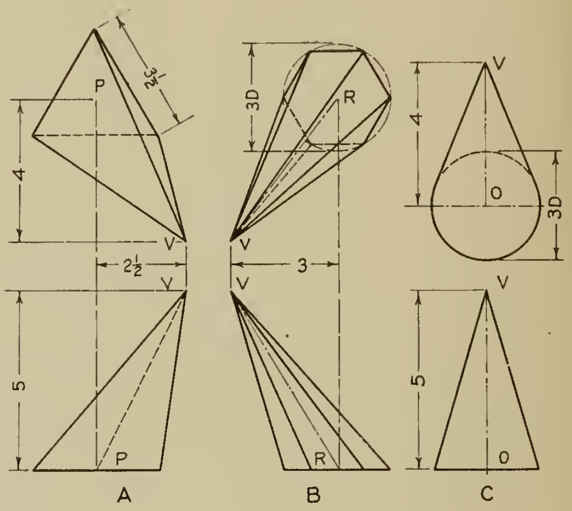


Figure 41-XII. Oblique Pyramids and Cone to be Truncated

## Group 2-XII. Intersecting Solids

1 to 3 inclusive, Figure 42-XII. Find the lines of intersection of the prisms and make the following developments:

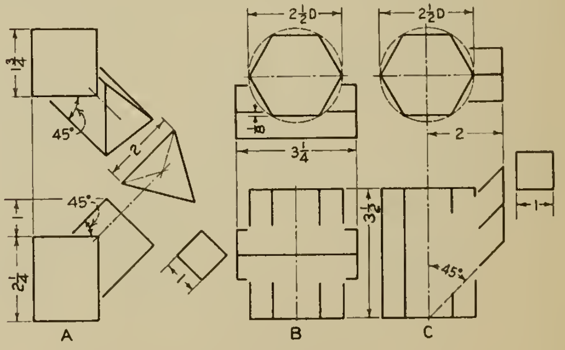


Figure 42-XII. Intersecting Prisms

(A) lateral surface of the triangular prism; (B) lateral surface of the square prism; (C) lateral surface and right end of the square prism.

4 to 6 inclusive, Figure 43-XII. Find the line of intersection of the cylinders and make a development of the lateral surface of the 2 1/2-inch cylinder.

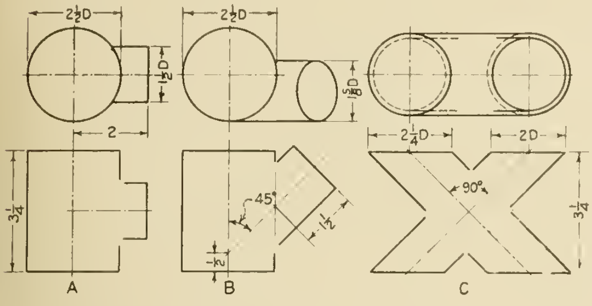


Figure 43-XII. Intersecting Cylinders

7 to 9 inclusive, Figure 44-XII. Find the lines of intersection of the objects and develop the lateral surfaces of the pyramids.

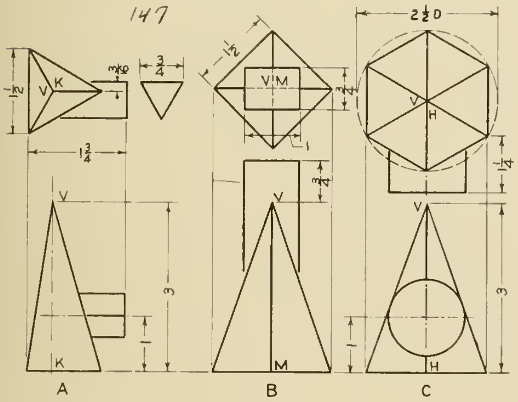


Figure 44-XII. Intersections

10 to 13 inclusive, Figure 45-XII. Find the lines of intersection of the objects and develop the lateral surface of the 3-inch cone.

## Group 3-XII. Convolute

1. Locate A in the center and to the left of the problem space. Point B is 3" directly below A. Point C is on the same level with B and 1" directly east of B. Line AB is the axis and C is the lower end of one turn of a right-hand helix of 3" lead. The helix is the directrix of a convolute included between two horizontal planes through A and B. Draw the front and top views of the convolute. Show the intersection between the convolute surface and the plane through B. Make a development of one turn of the convolute.

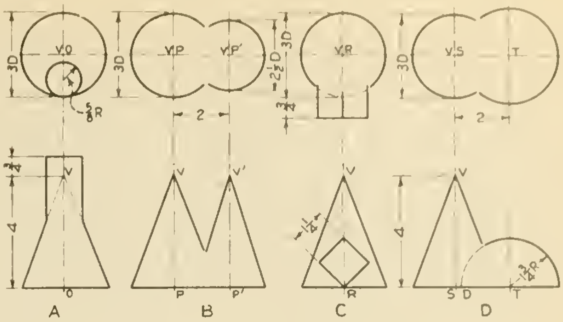


Figure 45-XII. Intersections

2. Draw a vertical cylinder, axis 2 3/4" long, diameter 2". Starting at the top and front of the cylinder, draw a left-hand helix with a 2 3/4" lead. The helix is the directrix of a left-hand convolute included between the planes of the two bases of the cylinder. Draw the front and top views of the convolute. Show the intersection between the convolute surface and the plane of the upper base of the cylinder. Make a development of one turn of the convolute.

## Group 4-XII. Transition Developments

1 to 5 inclusive, Figure 46-XII on the following page. Develop the lateral surface of the transition section as shown. Note: If transition sections are properly cut, a half development of objects B, D, and E will be sufficient

6. Locate A to the left and near the center of the problem space. Point B is 3 1/4" directly north of A and on the same level with A. Draw a 1 3/8" frontal circle, center at A, and a 4 1/4" frontal circle, center at B. Locate C at the bottom of the front circle. Locate D and E 120° from C on the front circle. Points C, D, and E are each the center of an arc which passes through the other two points. The three arcs form the front end, and the large circle forms the other end of a transition piece. Divide the surface into cones and convolutes in the front, top, and right side views. Make a development and show

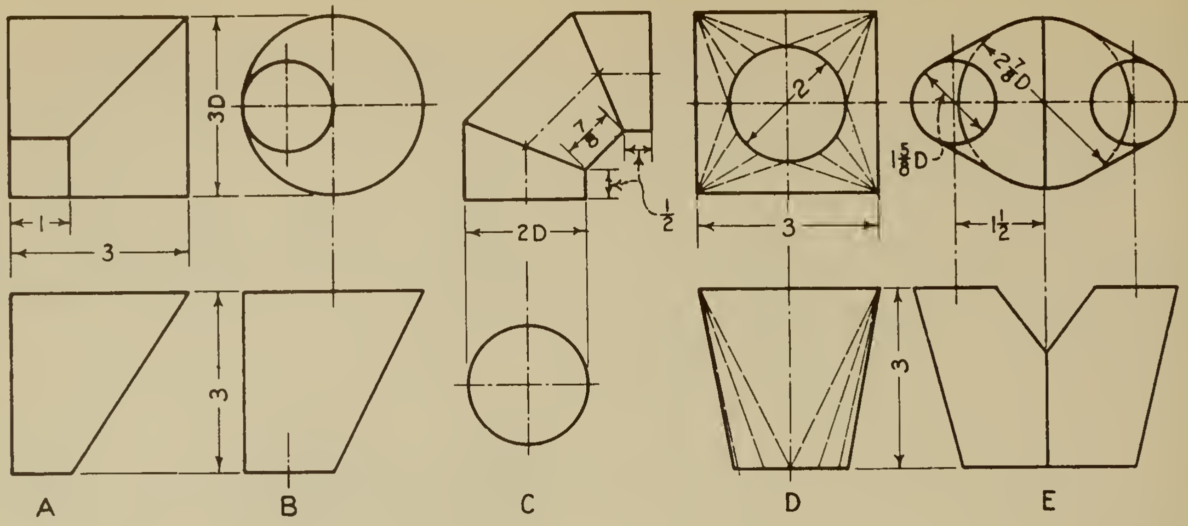


Figure 46-XII. Development of Transition Sections

the position in all three views of two equally spaced intermediate ribs.

7. The following data are for Figure 19-XII. Point M is 2 1/4" directly back of N. Major axis of the front ellipse is 4", minor axis is 2 1/4". Change the circle to an ellipse, major axis vertical and 1 7/8" long, minor axis 1 1/4" long. Draw the front, top, and right side views of the convolute transition piece and make a development.
8. Scale 1" = 1'-0". The following data are for Figure 20-XII. Omit that portion of the cowl which lies below points A, B, and D. Length of hood 4'-3". Length of axes: CD = 2'-3", AB = 3'-9". Draw a front, top, and right side view of that portion of the hood which lies above points A, B, and D, and make a development of the surface. Show the location in all views of two equally spaced intermediate supports. Starting at the top and front of the cylinder, draw a left-hand helix with a 2 3/4" lead. The helix is the directrix of a left-hand convolute included between the planes of the two bases of the cylinder. Draw the front and top views of the convolute. Show the intersection between the convolute surface and the plane of the upper base of the cylinder. Make a development of one turn of the convolute.
9. The hopper of Figure 46-XII (A) is intersected by a 1" cylindrical conveyer. The center line of the cylinder pierces the rear face of the hopper and extends 1" to the rearward (north) of the upper base of the hopper as seen in the top view. Also in the top view, the center line of the cylinder is 3/4" from the left surface of the hopper and parallel to the left surface. In the front view, the center line of the conveyer is seen as a point 3/4" from the upper base of the hopper. Altitude of the hopper is 4" instead of 3". Draw the front and top views of the object and make a development of the conveyer and hopper.
10. The hopper of Figure 46-XII (B) is cut by a plane which is perpendicular to a frontal plane and makes an angle of 75° with the extreme right-hand element of the hopper (as seen in the front view). The plane cuts the axis of the hopper 2" above the lower base. Altitude of the hopper is 4" instead of 3". Draw the front and top views of the truncated object and make a development of the lower (truncated) part.

## Group 5-XII. Hyperbolic Paraboloid

1. Locate A in the center of the problem space and to the extreme left. Point C is 2" east of A, 4" below A, and 1" south of A. Line AB has a bearing of N 20° E, and the top view is 5 1/2" long. Point B is 1" below A. Line CD has a bearing of S 80° E, and the top view is 5 1/2" long. Point D is 2" above C.

Lines AB and CD are the directrices

of an hyperbolic paraboloid. Lines AC and BD are elements of one ruling. Through B pass a horizontal plane, and through C pass a frontal plane. Show the intersection of the warped surface and these two planes.

2. Locate A in the center of the problem space and 3" from the left border. Point B is on the same level with A and 2 1/2" directly east. Point C is 2" directly north of B and 3" directly above B. Line CD is level and D is 5" directly east of C. Point E is 3" directly below D.

   AB and the west half of CD are the directrices of one hyperbolic paraboloid. Line AE and the east half of CD are the directrices of another hyperbolic paraboloid. In the front, top, and right side views show 12 profile elements of each surface. Draw three frontal planes located in front of CD and 3/4", 1 1/4", and 1 1/2", respectively, from CD. Find the lines of intersections between the three planes and the two warped surfaces.

3. Design the skirts, i.e., the two hyperbolic paraboloid surfaces which lie below the points A, B, and D, of Figure 20-XII. See Ex. 8, Gr. 4, Ch. XII for comparative data. Supply your own dimensions and other data. Show planes R and T as indicated. Make a development of one of the surfaces.

   Note: In practice the convolute surface of Figure 20-XII would ordinarily be joined to the hyperbolic paraboloidal surfaces by a tangent surface. The tangent surface is often a segment of an elliptical, oblique cone. The conical surface may be omitted in this design.

4. Scale 1/4" = 1'-0". The earth section of an irrigation canal is a trapezoid; bottom width 8', side slopes 1 1/2:1; depth of section 7'-9". Through a rock cut, the canal was changed to a rectangular section; bottom width 14', depth 7'-9". Both sections are in open cut, and the rock section is concrete-lined. The transition section, which changes from a trapezoid to a rectangular opening, is made of concrete and is 12' long. The bottom of the transition is level. Draw the front, top, and right side views of the transition. Make a development of one of the hyperbolic paraboloidal surfaces. Show sections cut by a plane 4' from either end and perpendicular to the center line of the ditch.

   Note: Since the structure is symmetrical about a vertical plane through the center line of the ditch, half views, taken on either side of the plane, will be sufficient.

## Group 6-XII. Conoid

1. Line AB is horizontal. Point B is on the same level with A and 3" due east of A. Point C is 1 1/2" due east of A and 4" below AB. Line AB is one directrix and a 3" horizontal circle with center at C is the other directrix of a right conoid. Draw the conoid in three principal views with profile elements spaced 1/4" apart. Show the intersection of the surface with two horizontal planes located 1 1/4" and 2 3/4" below AB.
2. A 4" frontal square and a 4" frontal circle are the open ends of a transition piece. The center of the circle is 3" directly north of and on the same level with the center of the square. Draw three principal views of the object. The design consists of triangles and convolutes. Show sections cut by two frontal planes spaced symmetrically between the ends.
3. Point B is 3" due east of A and on the same level with A. Point C is 2" due south of the center point of line AB and 2" below AB. Line AB is the north edge of a 3" x 4" horizontal rectangle. Point C is the center of a 5" horizontal circle. These sections are the open ends of a pipe connection. The sides of the rectangle are to be joined to arcs of the circle with conoidal surfaces having frontal and profile elements. Draw the front and top views of the connection. Show the line of intersection between the surface and a horizontal plane 1" above C.
4. Point B is 2" south and 3" east of, and 1" above, point A. Point C is 2" due south of, and 3" below, A. A straight line directrix of an oblique conoid includes line AB. The curved line directrix is a 3" horizontal circle with center at C. The vertical plane director passes through the mid point of AB and point C. In three principal views show 16 equally spaced elements. Show the intersection of the surface with two horizontal planes spaced 1" and 2" above C.

## Group 7-XII. Cylindroid

1. Point B is 2 1/2" north of and 2 1/2" directly above A. Draw the upper half of a 3 1/4" frontal circle, center at A. Draw the upper half of a 3 1/4" profile circle, center at B. The director plane is vertical and passes through AB, and the two

semicircles are the directrices of a cylindroid. Show twelve equally spaced elements in three principal views. Pass a plane through the mid point of AB and perpendicular to AB, and show the intersection with the cylindroid in all views.

2. Point B is 3" north of, and 2 1/2" directly east of A. Draw the upper half of a frontal ellipse with center at A, major axis horizontal and 2 1/2" long, and the minor axis 1 3/4". Draw the upper half of a profile ellipse with center at B, major axis horizontal and 2 1/2" long, and minor axis 1 3/4". The director plane is horizontal and passes through AB, and the two semiellipses are the directrices of a cylindroid. Show twelve equally spaced elements in three principal views. Pass a plane through the mid point of AB and perpendicular to AB, and show the intersection with the cylindroid in all views.
3. Same as exercise 1 above, except that the plane of the profile directrix is perpendicular to AB.
4. Same as exercise 2 above, except that the plane of the profile directrix is perpendicular to AB.

## Group 8-XII. Helicoid

1. Point B is 3" directly below A. Line AB is the axis of a right helicoid, 3" lead, and right hand. In the front and top views show one turn of the helicoid which lies between two cylinders of 1 1/2" and 4" diameters. Space elements 1/4" apart.
2. Same as exercise 1 above, but draw a left-hand helicoid.
3. Point B is on the same level with, and 2" due north of A. Line AB is the axis of a right helicoid, 2" lead, and right hand. In the front and top views show one turn of the helicoid which lies between two cylinders of 2" and 5" diameters. Space elements 1/8" apart.
4. Same as exercise 3 above, but draw a left-hand helicoid.
5. Point B is 4" directly below A. Line AB is the axis of an oblique, right-hand helicoid. The helical directrix has a lead of 1 1/2" and diameter 2". The elements are 1" long, make angles of 60° with the axis, slope down and outward, and are spaced 1/8" apart on the axis. Draw the front and top views and show two turns of the helicoid.
6. Same as exercise 5 above, but draw a left-hand helicoid.

## Group 9-XII. Pipe Ells

1. Point B is on the same level with and 2" due east of A. Point C is 3" east, 1" north, and 3" above A. Point D is on the same level with, and 2" due north of C. Line AB is the upper edge of a frontal square. Line CD is the upper edge of a profile square. These squares are the open ends of a pipe ell of uniform vertical cross section. Draw elements in the front and top views spaced 1/4" apart. Make a development of the upper surface and one of the smaller cylindrical surface.
2. Point B is on the same level with, and 2" due east of A. Point C is 1 1/2" due west of, and 1" below A. Point D is 3 1/2" directly above C. Line AB is the upper edge of a 1" x 2" frontal rectangle. With CD as an axis, generate a quarter-turn pipe connection by revolving the rectangle at a uniform rate of speed until AB is at the same elevation as D. The direction of motion is upward and to the rear. Draw elements in the front and top views spaced 1/4" apart, vertically. Make a development of the upper surface.

## Group 10-XII. Conveyors

1. A 1" horizontal-profile cylinder is the shaft of a right-hand screw conveyor. The surface is a right helicoid, 3" outside diameter, 1" inside diameter, and lead 2". In the front and top views show elements spaced 1/4" apart for two full turns of the conveyor.
2. Same as exercise 1 above, but draw a left-hand conveyor.

## Group 11-XII. Stairs

1. Scale 1/2" = 1'-0". Draw the front elevation and plan of a helical stair constructed about a 36" steel column. The outside foot guard is made of sheet metal, cylindrical, 9'-0" in diameter, and 36" vertical dimension. In going once around, the stair gains an elevation of 6'-0". The turn is right hand. The treads measure 6" x 12" in place. The 6" dimension is vertical. Show one complete turn of the stair.
2. Same as exercise 1 above, except that the stair turns left hand.
3. Draw a front elevation and top view of one turn of the stair described in Ex. 6, Gr. 14, Ch. XI. The helical lead is 26'-0". The turn is right hand.

4. Same as exercise 3 on the preceding page, but draw a stair of left-hand turn.

### Group 12-XII. Ramps

1. Scale 1/8" = 1'-0". Draw a plan and an elevation of a quarter turn, right-hand ramp entrance for a garage. The driving surface is a right helicoid lying between two coaxial cylinders of 12'-0" and 48'-0" diameters. In making one complete turn, an elevation of 20'-0" is gained. A hub guard, lying in the surface of the outer cylinder, is to be constructed with a maximum vertical dimension of 36". Draw elements in the driveway and hub guard spaced 2'-0" apart, vertically.
2. Same as exercise 1 above, but draw a left-hand ramp.

### Group 13-XII. Screw Threads and Springs

1. On a frontal-horizontal cylinder, 3" long, diameter 1", draw a square thread (right-hand, right, helicoidal surface). Helical lead 1". Single thread. See Figure 3-XIII (page 157).
2. Same as exercise 1 above, but draw a V-sharp thread. See also Figure 29-XII.
3. Draw 3 turns, one in section, of a helical spring made of 3/8" square stock. Outside diameter 3", helical lead 1 1/4". See Figure 37-XII. Draw a right-hand spring.
4. Same as exercise 3 above, but draw a left-hand spring.

### Group 14-XII. Hyperboloid of Revolution

1. Line AB, with 4" horizontal circles at A and B, is the axis of a hyperboloid of revolution. The gore circle is 1" in diameter. Show sixteen elements, double-ruled, in the front and top views. Use a total of 32 elements.
2. Point B is 1" due south and 4" below A. Line AB is the axis of the upper half of an hyperboloid of revolution. The 3" horizontal base circle is at A. The 1" horizontal gore circle is at B. In the front and top views, show sixteen elements, double-ruled. Use a total of 32 elements.
3. The center line AB of a 1/2" shaft is frontal-horizontal. The center line CD of a second 1/2" horizontal shaft is 1 3/4" above AB and has a bearing of N 30° E. The element common to both gears is a horizontal line, and its top view bisects the angle between the center lines of the two shafts in the top. Two equal skew gears are mounted on the shafts, each 3" long. On the rolling surfaces of the gears, which are hyperboloids of revolution, show sixteen elements per gear, per ruling, or a total of 64 elements. Omit the shafts, but show the holes through the gears. The key ways are 1/16" x 1/8". The 1/16" dimension is radial.

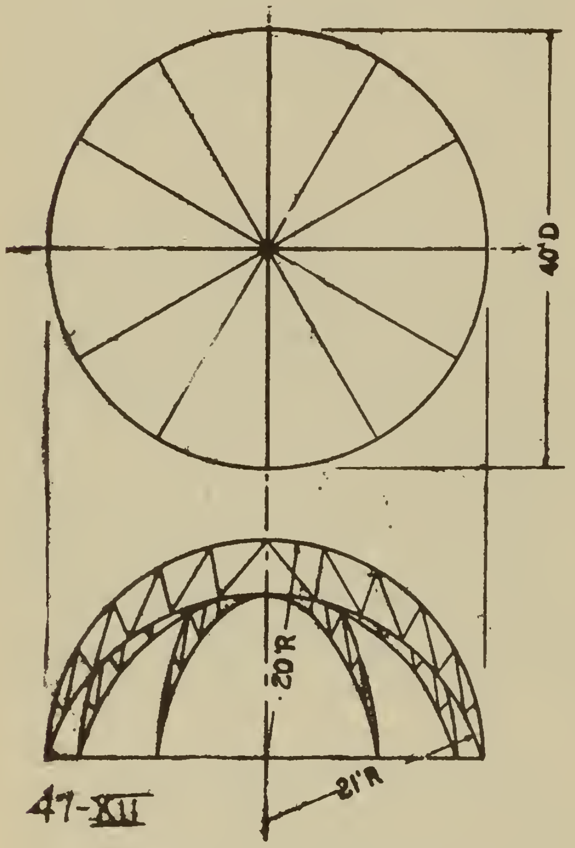
### Group 15-XII. Sphere Intersections

1. Point A is the center of a 3" sphere. Point B, the center of a 4" sphere, is on the same level with A, but 1" north and 2" east of A. In the front and top views, show the line of intersection between the two spheres.
2. Point B is on the same level with, 1/2" south and 1" west of, A. Point C is 1" east of, 1" north of, and 1" above, A. At A draw a 3 1/2" sphere. At B draw a 3" sphere. At C draw a 2" sphere. In the front and top views of sphere A, show the holes that must be cut to admit the other two spheres.
3. Draw a 3" sphere, center at A. Through point B, which is 1 5/8" east of, 1 3/8" north of, and 1" above A, draw a plane with a strike of N 70° E and a dip of 55° forward. In the front and top views locate the line of intersection on the sphere.
4. Make a front and top view drawing of a rounded hexagonal bolt head, Figure 34-XII. Distance across corners 3 1/4". Height of prism 2 3/4".
5. Point B is on the same level with, and 4" due east of, A. Point C is on the same level with, and is 1" due north of the mid point of line AB. Draw a 3 1/2" sphere at C and a 1 1/2" cylinder with axis AB. In the front and top views of the sphere, locate the line of intersection between the sphere and the cylinders.

### Group 16-XII. Sphere Development

1. Make an approximate development of a 4" sphere. Use 1/2" zones.
2. Make an approximate development of a 5" sphere. Use sixteen meridian strips.
3. Using the zone method, make an approximate development of the larger sphere of Ex. 1, Gr. 15, Ch. XII. In the development disregard that part of the surface intersected by the smaller sphere.
4. Same as exercise 3 above, but use the meridian method.

5. Using the zone method, make an approximate development of the sphere of Ex. 5, Gr. 15, Ch. XII. In the development disregard that part of the sphere intersected by the cylinder.
6. Same as exercise 5 above, but use the meridian method.
7. Scale 1/4" = 1'-0". A steel water tank supported on a tower has a hemispherical bottom, 16'-0" in diameter. The tank is filled through a 24" cylindrical riser pipe which enters from underneath. Divide the hemisphere into sixteen meridian sections and show approximate development of one section.
8. Scale 1/8" = 1'-0". Draw a plan and front elevation of the north half of the hemispherical dome of Figure 47-XII. The dome is to be covered with sheet metal laid in five zones. Show the necessary patterns for the approximate development by zones.



47-XII

Figure 47-XII. Spherical Dome

### Group 17-XII. Ellipsoid

1. Draw a frontal ellipse with major axis 4" and horizontal, and minor axis 1 1/2". In the front, top, and right side views show a prolate ellipsoid generated by the ellipse. Show the intersection of the surface with a frontal plane 3/4" in front of the major axis and a profile plane 3/4" to the right of the minor axis.
2. Same as exercise 1 above, but generate an oblate ellipsoid.
3. Line AB has a bearing of N 30° E and a slope of 4:12, down and to the north. About AB as an axis, generate an oblate ellipsoid, major axis 3 1/2", minor axis 1 1/4". Show the line of intersection between the surface and a plane perpendicular to the axis and 3/4" north of the intersection of the major and minor axes.
4. Same as exercise 3 above, but generate a prolate ellipsoid.

### Group 18-XII. Annular Torus

1. An annular torus is generated by a 1" circle which lies in a vertical plane. The plane of the circle passes through AB, a vertical axis about which the circle is revolved. The center of the circle is 1 1/2" from AB. Draw three principal views of the torus. Point C lies on AB and in a horizontal plane which rests on the uppermost part of the torus. Through C pass an oblique plane with a strike of N 60° E and a dip of 30° forward. Locate, in all views, the line of intersection between the plane and the annular torus.
2. Draw the annular torus described in exercise 1 above, except that the axis and plane of the circle are perpendicular to the profile. Draw a 3" cylinder, 2" long, and axis perpendicular to the profile. The cylinder intersects the torus and is tangent to the ring at some point on the outer circumference. Show, in all views, the line of intersection between the two objects.
3. Scale 1/4" = 1'-0". A 48" pipe line, with a zero grade, bears due north. With a radius of 12'-0" the direction is changed to due west. The center line of a 36" branch pipe bears N 60° E from the mid point of the arc of the main pipe line. The center lines of the two pipes are on the same level and intersect.

   A special T-elbow connection is to be cast. It will extend from tangent point to tangent point on the 48" pipe (torus) and include 12" of the branch pipe (cylinder). The type of joint, i.e., bell and spigot, flange, or threaded, is to be omitted in this exercise. The thickness of the pipe is disregarded. The radius of curvature is taken to the center line of the pipe. Pipe diameters are inside measurements.

Required: (1) Draw a plan view and two elevation views; one elevation looking north and the other looking in the direction of the center line of the branch pipe. (2) Locate in all views the line of intersection between the two pipe lines. (3) Make a zone development of the entire connection. The development will be used to make a pattern from which a casting is to be made. (4) Same as exercise 3 above, except the invert of the branch is laid on a grade of 15:1000.

Required: (1) Draw necessary views, (2) and (3) as outlined in exercise 3 above, and (4) what is the angle between the center line of the branch pipe and a tangent to the 90°-elbow at the point where the two center lines intersect?

### Group 19-XII. Serpentine

1. Draw three turns, one in section of a helical spring made of 3/8" round stock. Outside diameter 3", helical lead 1 1/4". See Figure 37-XII (C).
2. Same as exercise 1 above, but use the straight line (conventional) representation. See Figure 37-XII (B).
3. Draw three turns, one in section, of a conical helical spring made of 3/8" round stock. Outside diameters: major 3", minor 1 1/4". Helical lead 1". See Figure 37-XII.
4. Same as exercise 3 above, but use the straight line (conventional) representation. See Figure 37-XII (A).

### Group 20-XII. Surfaces of Revolution

1. Scale 1" = 1'-0". The axis of a parabolic reflector is perpendicular to the profile. The maximum diameter is 48". The distance from the focus to the directrix is 9". The parabolic surface is intersected by a 6" vertical cylinder. The axis of the cylinder passes through the focus of the parabola. The cylinder intersects only the lower part of the surface and is not shown in the drawing. Show the line of intersection in three principal views.
2. Scale 1" = 1'-0". The axis of an hyperbola is perpendicular to the profile. The distance between the foci is 9". Generate an hyperboloid by revolving about the axis. Extend the branches of the curves 24" to either side of the directrix. The axis of a 24" cylinder coincides with the directrix of the hyperbola. The cylinder, symmetrical about the axis of the hyperbola, is 48" long. Show the line of intersection in three principal views.
3. Use one branch of the hyperbola described in exercise 2 above and revolve about the directrix. The axis of the cylinder coincides with the axis of the hyperbola, and the cylinder is symmetrical about the directrix. Show the line of intersection in three principal views.
4. Draw three principal views of the velocity diagram of Figure 27-IV (page 47). See Ex. 5, Gr. 2, Ch. IV. Revolve about CD as an axis. A plane passes through O, is perpendicular to the profile, and makes an angle of 30° with a frontal plane. Show the line of intersection in all views.
5. The curve $y = x(x + 1)(x - 2)$ crosses the x-axis at $x = -1$, $x = 0$, and $x = 2$. Revolve about the x-axis that branch of the curve which lies between $x = 0$ and $x = 2$. Represent the surface in the front and top views by locating a sufficient number of elements. Through the point $x = 1$, pass a plane which is perpendicular to the horizontal and makes an angle of 30° with the profile. Show, in all views, the intersection between the plane and the surface of revolution.

# CHAPTER XIII

## FASTENERS

1-XIII. Seldom, if ever, is an engineering structure monolithic. It is commonly composed of parts held together as a unit by certain devices called fasteners. The most common fasteners are (1) nails, glue, specially designed joints, seams, welds, and clamps; and (2) bolts, screws, rivets, pins, keys, and locking devices. Only the fasteners listed in the second part of the above classification will be considered here, not because they are more important, but because special treatment is necessary properly to represent them in convention according to good drafting room practice. Emphasis is laid upon the fasteners having screw threads, owing to the necessity of having standard thread representations. Screw threads (helical threads) are to be distinguished from scroll threads. Screw threads are cut to the outline of the helix, a space curve, Figure 23-IV. The outline of the scroll thread is the spiral of Archimedes, a plane curve, Figure 19-IV. Screw threads are used on bolts and screws for the transmission of power or motion and for making adjustments.

2-XIII. Thread Nomenclature. Figure 1-XIII (A) illustrates in pictorial an American (National) Standard hexagonal bolt. The curve of the thread is a cylindrical helix. The diameter is the size of the stock on which the thread is cut. The head and nut on this particular bolt are hexagonal. The nominal length of the bolt is the length under the head. The length of countersunk screws, bolts, and studs is the total length. The length of the thread--usually 1 1/2 diameters + 1/4 inch --is indicated by the lower-case letter. The diameter at the root of the thread is called

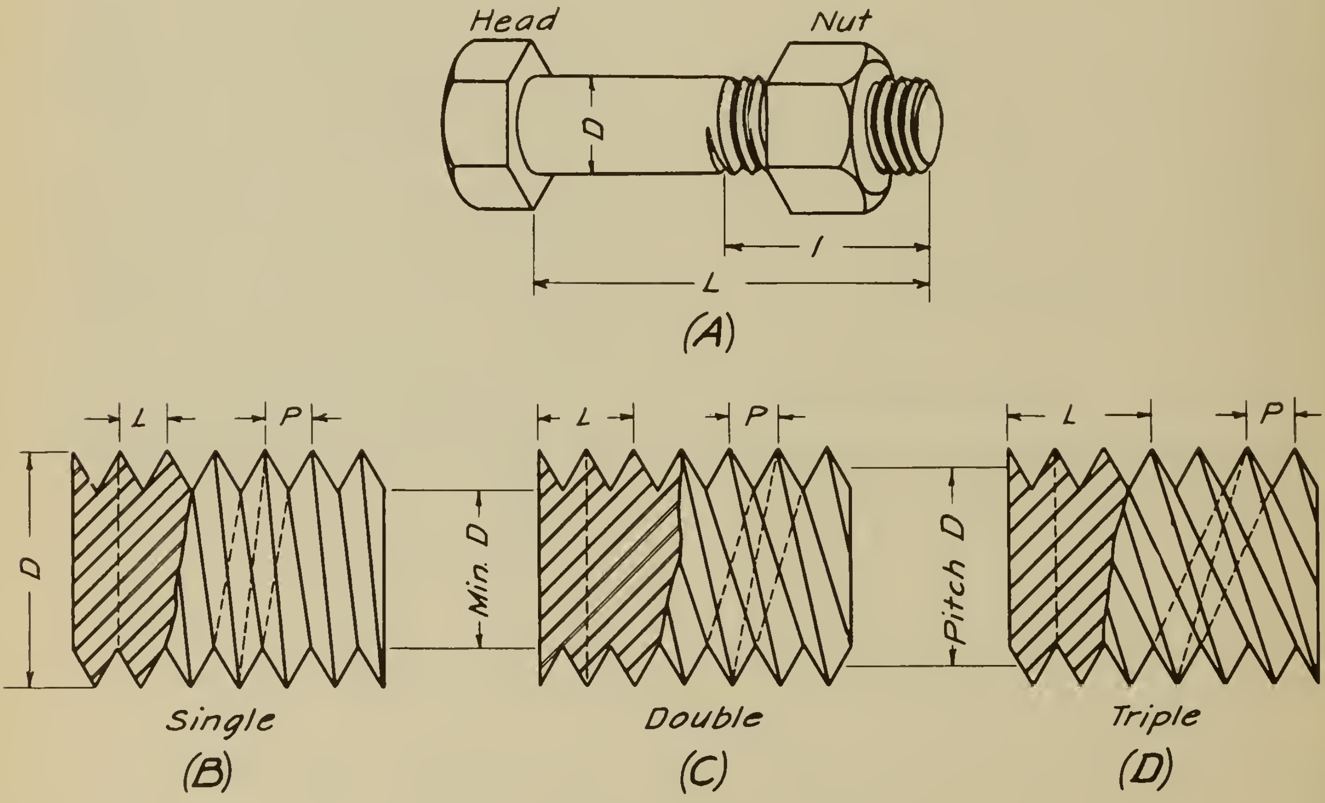


Figure 1-XIII. Screw Thread Nomenclature

the minimum diameter, drawing (C). The diameter midway between the over-all and the minimum diameters is called the pitch diameter, drawing (D).

Lead is a term applying to the helical curve and is defined in Article 20-IV. Pitch is a term relating to the actual thread. It is the distance from a point on one thread to the corresponding point on the adjacent thread. The terms pitch and lead should not be confused.

Threads are understood to be right hand and single unless otherwise stated. Left-hand and multiple threads are so marked on the drawing. A single thread has only one thread cut on the stock (cylinder). If a more rapid advance along the axis is desirable and a coarse thread is to be avoided, two or more threads are cut side by side, giving a multiple thread equal in strength to a fine thread series and the rapid motion of a coarse thread.

The relation between lead and pitch can now be stated: They are (1) L = P if the thread is single, (2) L = 2P if the thread is double, and (3) L = 3P for a triple thread, Figure 1-XIII.

In the construction of threads (B), (C), and (D), Figure 1-XIII, it should be noticed that (1) the upper crest of the single thread is opposite the lower trough, (2) the upper crest of the double thread is opposite the lower crest, and (3) the upper crest of a triple thread is opposite the lower trough. The threads illustrated are all right hand, and the front lines all slope to the right. The thread outlines on the back side, however, slope in the opposite direction. Left-hand threads slope in an opposite direction to the slope of a right-hand thread.

3-XIII. Thread Standards. The section outline of a thread will depend upon the use to which it is to be put. Some of the more common forms are illustrated in Figure 2-XIII on the following page. (See Appendix for tables giving threads per inch):

The Sharp-V thread is not widely used. Its close fitting form--with resulting friction--makes it desirable for adjusting screws on high precision instruments and to increase the holding power of set screws.

The American National thread has a sharp-V form with the crests and troughs flattened or filled in as indicated. This thread was formally known as Seller's profile. It was known later as the United States Standard. The American Engineering Standards Committee --later called the American Standards Association--approved specifications which fixed the dimensions for all sizes of our National threads. Two threads were adopted--a coarse and a fine series. A third--a special series --is recommended. The special series has an extra fine thread for use on fasteners where light sections, fine adjustments, jar, and vibration are important factors. These three series are called our National threads, NC, NF, and NS, respectively, and supersede the former U.S.S., A.S.M.E., and S.A.E., threads. See tables in Appendix for threads per inch.

The Square thread is used for transmitting power or motion, parallel to the axis. The V threads are not suitable for this purpose as part of the thrust transmitted is not parallel to the axis and therefore tends to burst the nut. It is evident that the square threads can have only half the number of threads per unit length as the V threads, when the pitch is the same for both. Therefore, the square thread is only half as strong in shear (stripping strength) as the V threads. A modification often used is the Acme thread. It is much stronger than the square, more easily cut, and permits the use of a disengaging or split nut--as the lead screw of a lathe--which can not be used on a square thread. The Brown and Sharpe Worm thread is used for the transmission of power to a worm wheel. It resembles the Acme thread but has a longer tooth.

The Buttress or breechlock thread--used to take the recoil in guns--transmits power in one direction only. It has the advantage of the square thread and the strength in shear of the V threads.

The Whitworth thread is the British standard. The British Association Standard--similar to the Whitworth--is used for small screws. These two threads have rounded crests and troughs which tend to reduce wear. A comparison should be made with the American threads.

The Knuckle thread is very loose fitting. It is often rolled in sheet metal or is cast. The depth of thread is sometimes very shallow, as in electric fixtures. It is also used in screw caps, threads cut in wood fixtures, and the like.

The Pipe thread is very common. It is loose fitting and classed as a cylindrical thread, since it is cut on a cylinder, although it has a slight taper. The taper allows for a "jam" in the fitting, Figure 4-XIII (C). The threads are filled with a heavy lead preparation in order to make a tight joint when jammed.

The French Standard and the International Standard have the American Standard form but are dimensioned in the metric system.

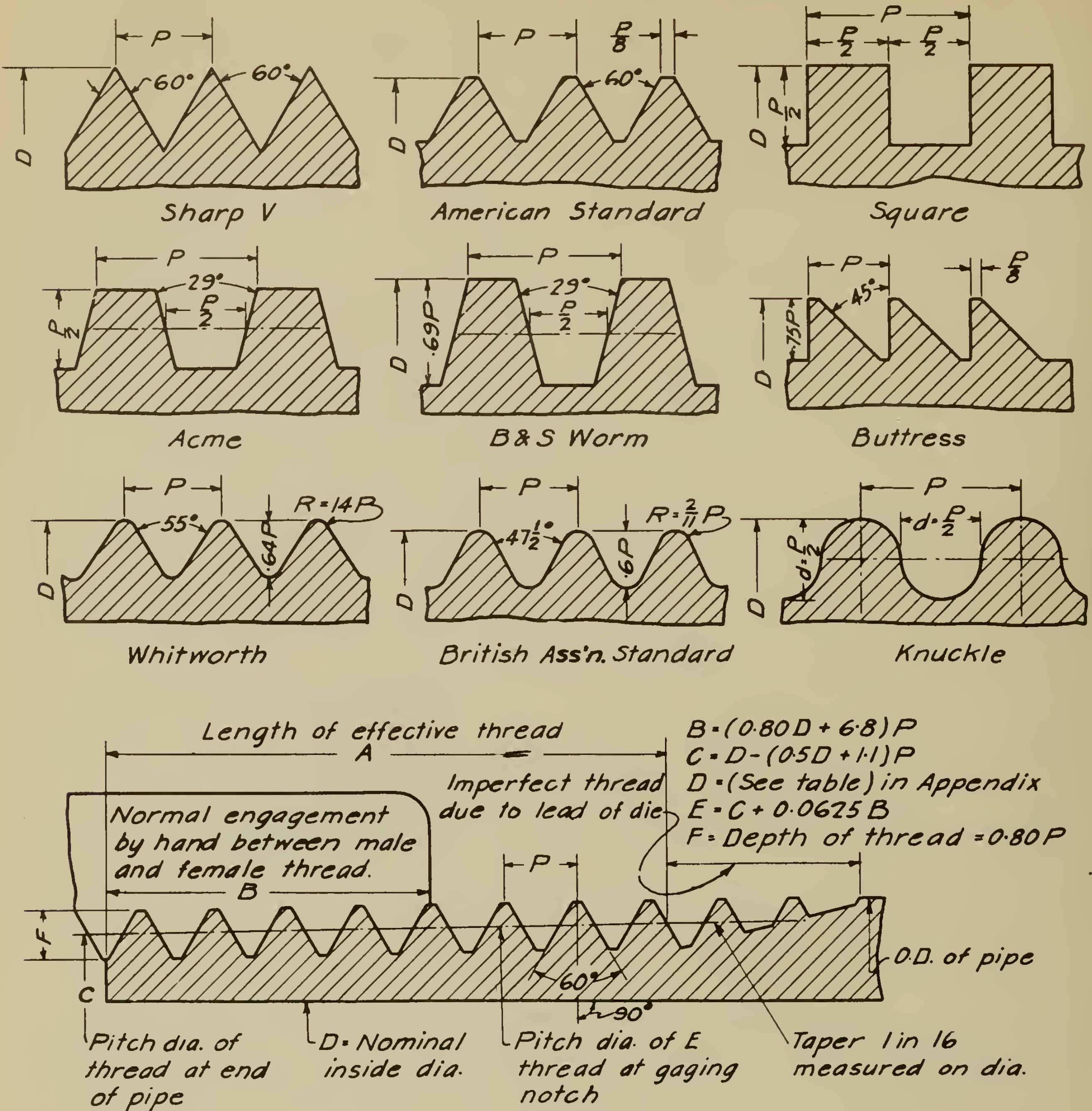
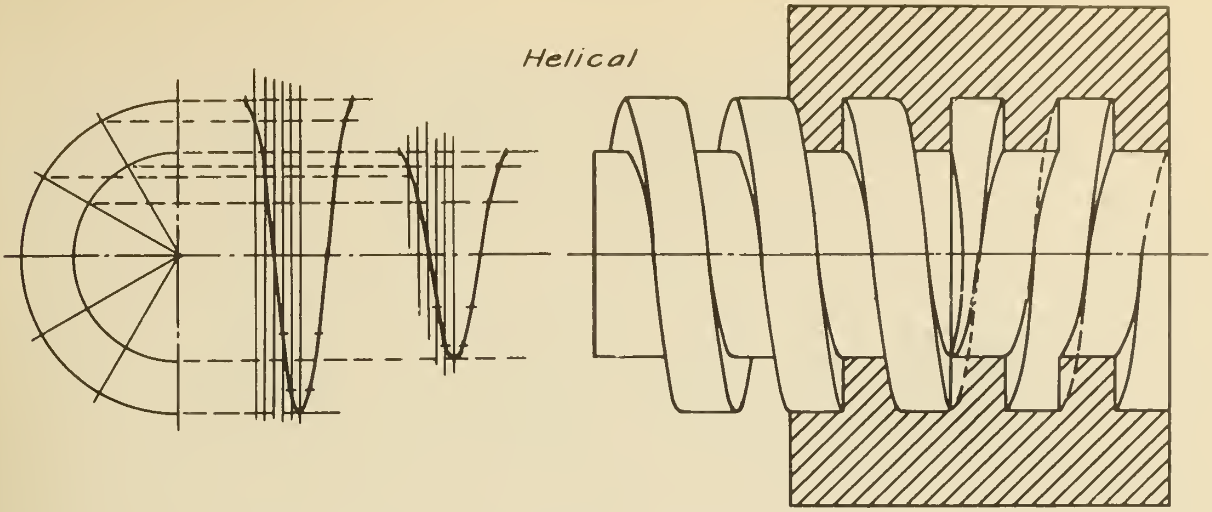


Figure 2-XIII. Various Screw Thread Forms

4-XIII. Thread Representation. A true representation of a square thread is shown in the upper drawing of Figure 3-XIII, on page 157. It will be noticed that the outlines are helical curves. Reference should be made to Figure 23-IV for method of drawing helical curves. The curves in the upper left-hand corner of Figure 3-XIII will then be self-explanatory. These curves are one turn of the helix and represent the crest and root outlines of the thread. The pitch for both curves is the same, although they have different diameters. If many turns of the thread are to be drawn, a templet may be cut from cardboard or thin wood and the curve thereby laid out on the drawing. Or the curve may be drawn as shown at the left and then transferred to the bolt drawing at the



External and Internal Square Thread

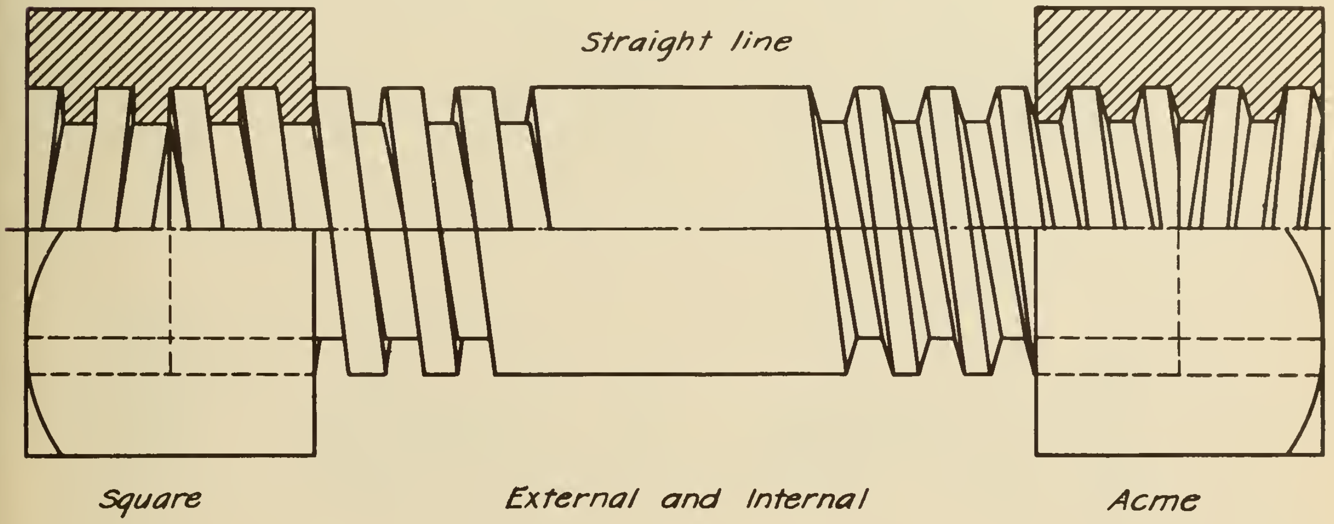
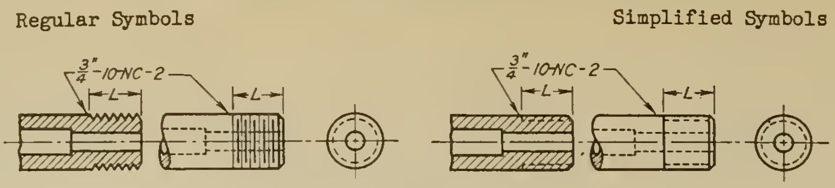


Figure 3-XIII. Thread Representation—Large Diameter

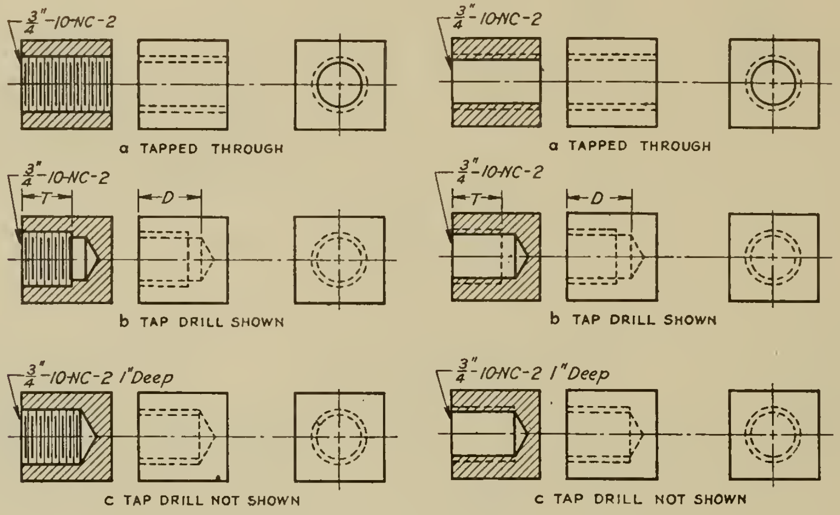
right by selecting a sufficient number of points on the branches of the left-hand curves and transferring them horizontally to the right by means of the T-square and dividers. The branches of the transferred curves should be spaced according to the required pitch.

The helical representation of threads is a laborious process and is done only for special reason. Instead, a straight-line representation is used--called the conventional helix. The lower drawing in Figure 3-XIII shows a straight-line representation of a square and an Acme thread. It should be noticed that in the three instances both the external and the internal threads are shown. The internal thread is on the inside of the nut and is sloped in the opposite direction from the external threads. Upon an examination of the square thread drawings, it can be seen that the threads on the bolt cut into the nut at an angle, causing an "overhang" which prevents the release of a split nut.

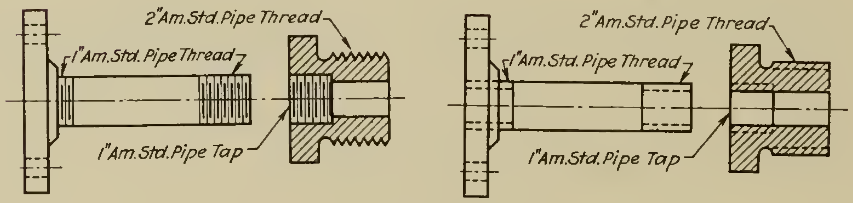
These representations, together with the straight-line V thread representations in Figure 1-XIII, (B), (C), and (D), are used when representing fasteners of large diameters, say larger than 1 inch. See also Figure 4-XIII (E). Hidden outlines should be omitted. For fasteners of smaller diameters, the conventional representation is used, Figure 4-XIII (A) and (B) on the following page. External and internal threads are shown. The



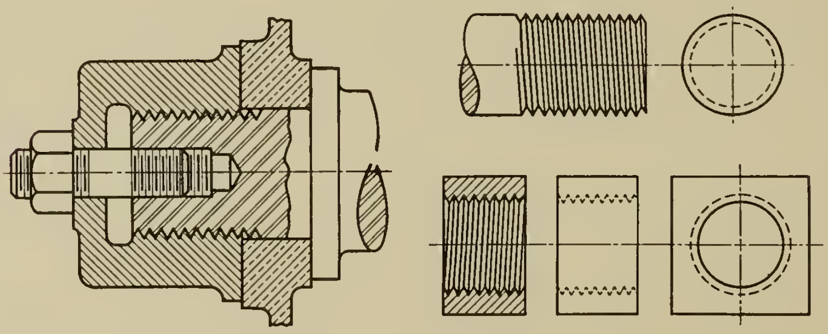
(A) External Threads



(B) Internal Threads



(C) American Standard Pipe Threads



(D) (E)

Figure 4-XIII. Conventional Thread Representation

internal threads are drawn in both plan and elevation. In the elevation drawings hidden outlines and section drawings are shown.

The foregoing conventions, Figure 4-XIII, apply to any standard thread. The pitch and depth of thread are not represented. It is evident then, when a conventional (straight-line) representation is used, the thread specifications, as outlined in Article 8-XIII, must be given.

5-XIII. American Standard Bolts. The American Standards Association has prepared specifications for standard bolts known as the American Standard Wrench Head Bolts and Nuts and Wrench Openings which have superseded the U.S. Standard and the S.A.E. Standard. They are designed in four series, i.e., hexagonal head bolt: (1) rough and semifinished, (2) finished; and the square head bolt: (3) rough and semifinished, (4) finished. It should be noticed (see Appendix) that the finished bolt heads and nuts are washer-faced, 1/64 inch thick; the rough and semifinished heads are 2/3 diameter high; the finished heads are 3/4 diameter high; and the width across flats of both the hexagonal and square head and nut series is 1 1/2 diameter for sizes above 3/4 inch. For dimensions below 3/4 inch, see tables in Appendix.

6-XIII. Studs. The stud, Figure 5-XIII, is a headless bolt with threads on either end. It is used when there is not room enough for a bolt and nut or a screw. It should be observed from Figure 5-XIII that the base is tapped while the hole in the cap is smooth and slightly larger than the stud. The bolt is screwed into the base by means of a special nut or wrench, the cap slipped on, and the standard nut replaced. Cylinder heads, for example, on steam or gas engines, water pumps, and the like are held in place by studs. In such instances, threads in the cylinder often rust in. If studs are used, the nuts can easily be removed and the cylinder head lifted off. Length of thread is the same on either end. The nominal length of a stud is the over-all length. Specified diameters of the base and cap, Figure 5-XIII, are the same, although the drilled hole in the cap is slightly larger than the tapped hole in the base. The manner of specifying threads is outlined in Article 8-XIII.

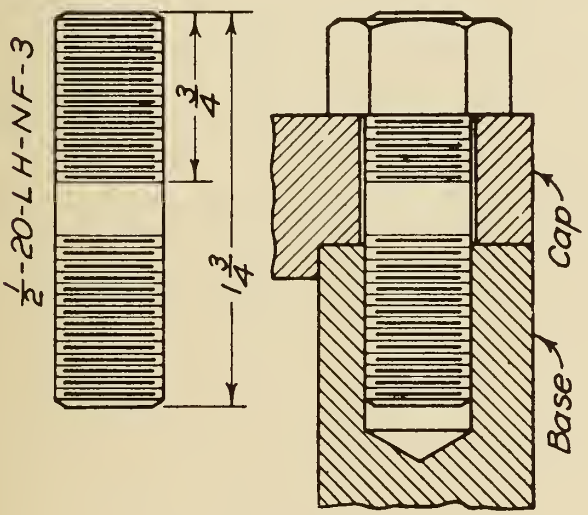


Figure 5-XIII. Studs

7-XIII. Screws. Screws are used for fastening two pieces together, Figure 6-XIII, by passing through a smooth hole in one piece and screwing into a tapped hole in the other, with the exception of the set screw. The latter passes through a tapped hole in one piece, a pulley for instance, and holds the piece in place by shoving the shaft against the back side of the pulley. A stud bolt functions as a screw, while the common bolt fastens two pieces together by gripping.

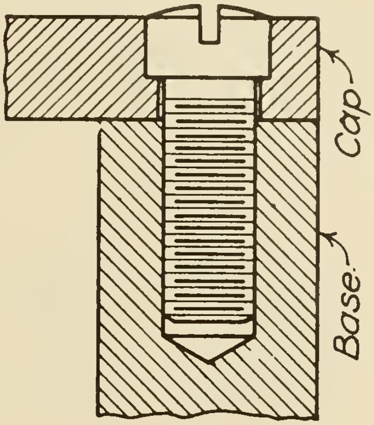


Figure 6-XIII. Screw

There are numerous forms of screws. The more common ones are (1) cap screws, (2) machine screws, (3) set screws, and (4) wood screws. Hexagonal heads are usually used on cap screws, square heads on set screws, and countersunk heads on wood screws, Figure 7-XIII. For other forms of screw heads, see Appendix. Machine screws are much smaller than cap screws. They are used on small parts and are specified by gage numbers. Set

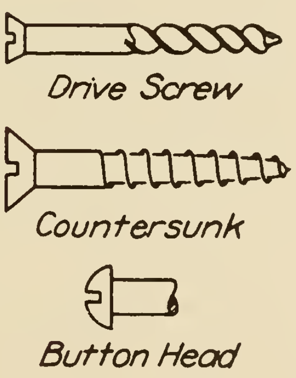


Figure 7-XIII. Wood Screws

screws are also small screws. When used on moving parts they are usually headless, unless concealed. Wood screws are used in woodwork. The outline of a wood screw thread conforms to a conical helix. A lag screw is a wood screw with a bolt head--usually square--used for fastening machinery to wooden parts. A bolt head is considerably larger than a screw head of the same geometrical shape.

8-XIII. Bolt and Screw Specifications. The numerous detail dimensions of bolt and screw heads and of the various threads, if standard, should not be placed on the drawing. Conventional specifications should be written which will furnish all the necessary information. The mechanic, when making the fastener, can then turn to the tables of standards and choose the proper dimensions.

The conventional specifications should include (1) the geometrical shape of the head and nut, (2) length of the fastener, (3) length of thread, (4) diameter of fastener, (5) number of threads per inch, (6) thread standard, and (7) class of fit. They are explained as follows (Figure 8-XIII):

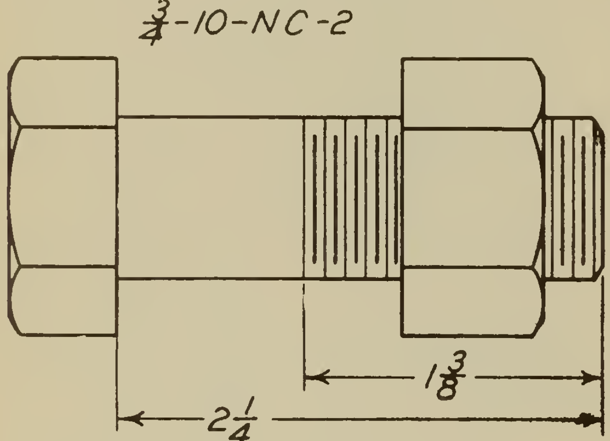


Figure 8-XIII. Bolt Specifications

(1) A fastener should be drawn in position one time and omitted in all other views. Since it is a conventional representation, only one view should be drawn. Heads and nuts should be drawn across corners. Then from one view the geometrical shape can be determined. Figure 8-XIII represents a hexagonal bolt with full specifications. Further specifications or dimensions should not be given, if the fastener is standard.

(2) The nominal length of the fastener is the length under the head. The nominal length of the countersunk fastener and of the stud is the over-all length.

(3) The length of thread recommended by the American Standards Association is 1 1/2 D + 1/4 inch. If practically the entire length is threaded, the length of the fastener is given and the length of thread omitted. The length of thread on either end of a stud should be the same.

(4) The diameter is seldom placed on the fastener. It should be written as the first item in the specifications. In Figure 8-XIII, the bolt specifications are written above the drawing. The diameter is 3/4 inch.

(5) The number of threads per inch will depend upon the thread standard, which has been described in a previous article. The second item of thread specifications gives the number of threads per inch. The bolt in Figure 8-XIII has 10 threads per inch.

(6) Thread standards are described in a previous article. If a nonstandard thread is specified--as is seldom the case--all thread details must go on the drawing. In Figure 8-XIII, a National thread, coarse series (NC) is called for.

(7) The American Standards Association has standardized the fit between bolt and nut into four classes as follows:

"Loose Fit (Class 1)--Recommended as a commercial standard for tapped holes in the numbered sizes only. May be used with screws of other classes to obtain quality of fit desired. (Sheet metal parts.)

"Free Fit (Class 2)--Includes the great bulk of screw thread work of ordinary quality of finished and semifinished bolts and nuts. (The common bolt.)

"Medium Fit (Class 3)--Includes the better grade of interchangeable work. (Automobile bolts and nuts.)

"Close Fit (Class 4)--Includes screw thread work requiring a fine snug fit. (High-grade airplane parts.)"

The bolt of Figure 8-XIII falls in the second class and is designated by the last item in the specifications--Class 2.

If the thread is double, Dub. is inserted in the specifications; if left hand, L.H. is inserted.

Thus, in Figure 8-XIII, the specifications are: Hexagonal bolt, 2 1/4 inches long, length of thread 1 3/8 inches, diameter 3/4 inch, 10 threads per inch, National Standard thread, coarse series, Class of fit 2. In Figure 5-XIII, the specifications are: stud, length 1 3/4 inches, length of thread 3/4 inch, diameter 1/2 inch, 20 threads per inch, left-hand thread, National Standard thread, fine series, Class of fit 3.

9-XIII. Miscellaneous Fasteners. Other common forms of fasteners used in machine and structural designs are (1) locking devices, (2) keys and tapers, and (3) rivets.

Some of the ordinary forms found in the above classification are shown in Figure 4-A in the Appendix. For standards, specifications, and detail dimensions, see an accepted handbook on machine design.

10-XIII. Helical Springs. The manner of representing and specifying helical springs is shown in Figure 9-XIII. Drawing C is the helical spring, and its surface is known geometrically as the serpentine. Drawings A (conical) and B (cylindrical) are straight line, or conventional, representations of the spring. Springs are often made of square or rectangular material instead of material of round sections.

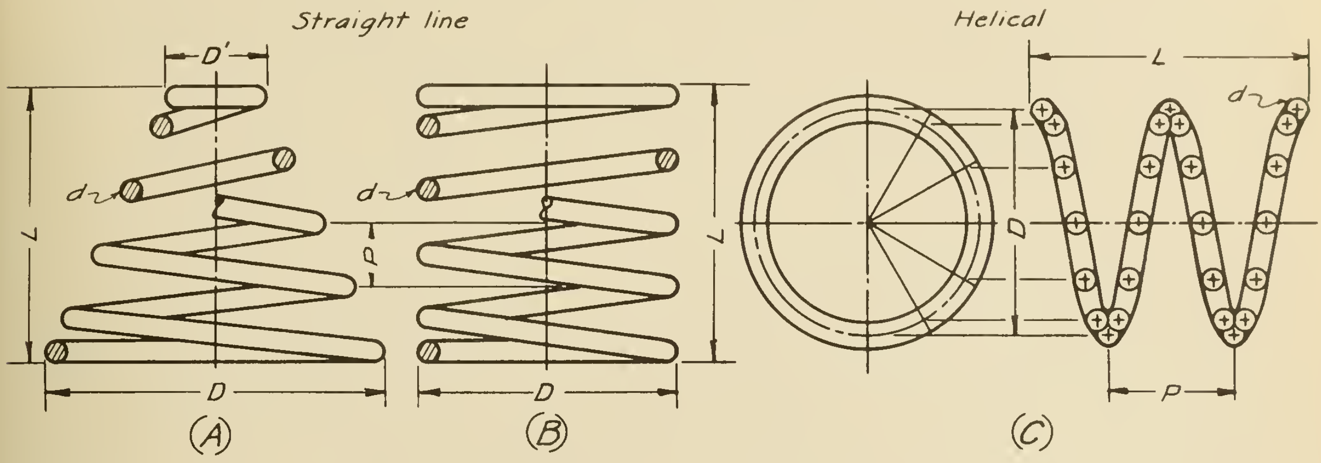


Figure 9-XIII. Spring Representations

EXERCISES

11-XIII. The space required for the following problems can easily be determined by the dimensions given. Scale 1" = 1".

1. Draw three turns of a helix, diameter 2 in., pitch 1 in.
2. Draw three turns of a conical helix, large diameter 3 in., small diameter 1 1/4 in., and pitch 1 in.
3. Draw three turns, one in section, of a helical spring made of 3/8 in. square stock. Outside diameter 3 in., pitch 1 1/4 in. See Figure 9-XIII (B).
4. Draw three turns, one in section, of a conical helical spring made of 3/8 in. round stock. Outside diameters: large 3 in., small 1 1/4 in. Pitch 1 1/4 in. See Figure 9-XIII (A).
5. Draw one view of an American Standard hexagonal rough bolt. Show the upper half of the nut in section, screwed halfway off the bolt. Use square threads instead of National. Show true helical representation of the thread. Diameter 1 1/2 in., length of bolt 3 1/2 in., pitch 3/8 in.
6. Same as exercise 5, except use: V-sharp thread, six threads per inch, double, left hand.
7. Same as exercise 5, except use: Acme thread, 5 1/2 threads per inch.
8. Same as exercise 5, except use straight-line representation instead of true helical representation.
9. Same as exercise 6, except use straight-line representation instead of true helical representation.
10. Same as exercise 7, except use straight-line representation instead of true helical representation.
11. Draw in section the following forms of screw threads, 1/2 in. pitch: (1) NC, (2) V-sharp, (3) square, (4) Acme, and (5) Whitworth.
12. Draw headless screws 2 in. diameter, 3 1/2 in. long as follows: (1) square thread, pitch 1/2 in.; (2) V-sharp thread, pitch 1/4 in.; (3) double, left-hand, V-sharp thread, 4 1/2 threads per in.; (4) double, left-hand, square thread, 2 threads per in.
13. Draw one view of an American Standard hexagonal rough bolt and nut. Diameter 7/8 in. Length 3 1/2 in. Use conventional NC threads.
14. Same as exercise 13, except show finished head.
15. Same as exercise 13, except draw square head.

16. Same as exercise 14, except use square head.
17. Draw four different cap screws, each with a different head. Name each head. Diameter 1/2 in. Length 1 3/4 in. Use conventional thread representation. Specify NC threads.
18. Same as exercise 17, except use machine screws and specify extra fine threads, left hand.

# CHAPTER XIV

## WORKING DRAWINGS

1-XIV. Drawings used by engineers or used in connection with engineering works are called engineering drawings. Working drawings are drawings which give complete information for the manufacture, construction, or operation and maintenance of a machine, structure, or engineering project, and should represent:

1. Shape description, i.e., a full graphical description of the object or structure.
2. Size description, i.e., the necessary dimensions of all parts.
3. A bill of material, notes, legend, specifications, and a descriptive title.

When composing a theme in any language, there should be included: (a) an introduction, (b) body, and (c) conclusion. In the composition of a structure in the graphical language, there should be:

1. An assembly drawing (introduction).
2. Detail drawings (body).
3. Bill of material, specifications, etc., (conclusion).

When making drawings of the simpler objects, item 1 above might be omitted, or 1 and 2 combined (assembly-working drawings). Perhaps only a part of 3 would be included. Figure 4-XIV illustrates a more simplified procedure, which is comparable to paragraph composition in another language.

A general classification of engineering drawings is as follows:

- I. Assembly
  - 1. Orthographic
  - 2. Pictorial
    - a. Section
    - b. Outline
    - c. Assembly-working drawing
- II. Detail
  - 1. Principal views
  - 2. Section views
  - 3. Auxiliary views
- III. Special
  - 1. Display drawings
  - 2. Erection drawings
  - 3. Diagram drawings
  - 4. Graphs

A description of the above classification will be given in the following articles.

It is necessary, in connection with structural drawings, to specify how the work is to be carried out, to supply notes and information concerning details and workmanship, and to furnish other information too voluminous to be placed on the drawings proper. Such specifications are written and bound separately but are considered a part of the drawings.

Working drawings are invariably executed in orthographic rather than pictorial. When making a selection of views in orthographic, the draftsman should use as many views as necessary in order to describe the object but should be careful to exclude views that are not needed. He should employ auxiliary views, cut sections, draw diagrams, and make pictorial views of difficult detailing, only when such presentations are needed to clarify the principal view drawings. Also, the recognized conventional representations should be employed whenever possible as a means of saving time and reducing labor.

The experienced draftsman will use conventions, inaugurate short cuts in his work, or employ idioms of drawing (violations of the strict theories of drawing), if by so doing his drawings are made clearer and easier to read, thereby reducing the probability of making errors in reading.

2-XIV. Assembly Drawings. An assembly drawing is a drawing of a machine, structure, or plant, assembled as a unit, showing the relative position of the various parts or units. Detailing and hidden outlines are usually omitted. Over-all dimensions or dimensions locating important parts or units are sometimes given. Assembly drawings may be drawn in orthographic or pictorial, depending upon the use to which they will be put. Orthographic assemblies may contain only one view, Figure 1-XIV on the following page, or might contain two or more views, Figures 2-XIV and 3-XIV. Sections are cut in order to bring out certain details and are used only for that purpose. Two or more views may be sectioned, or only a part of one view, depending upon the nature and amount of interior details to be shown. A presentation of this nature is called a section-assembly. If sections are omitted, it is called an outline-

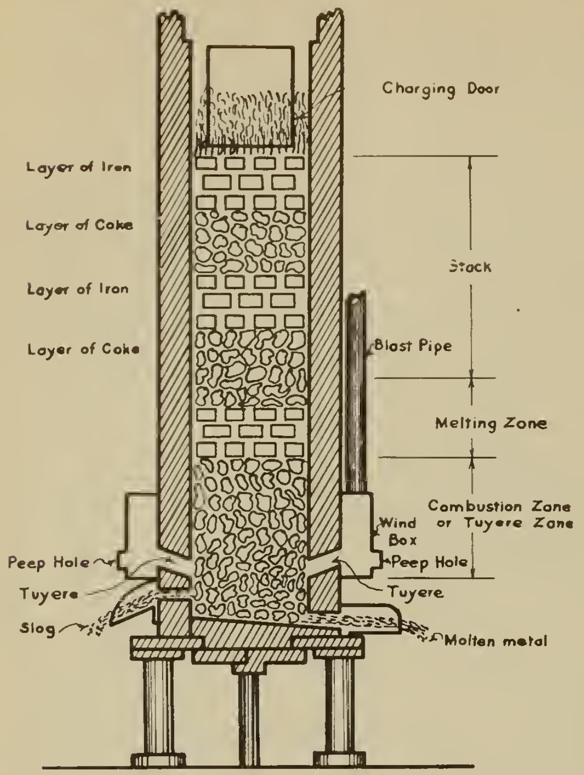


Figure 1-XIV. One-View Assembly

assembly, Figure 2-XIV on page 165. A plant-assembly is shown in Figure 3-XIV. A block-plan shows the relative positions of a group of buildings or a building with the positions of its different wings and the service connections, such as water, sewers, wiring, etc.

Assembly drawings of small parts are often executed in two or more orthographic views, including sections and auxiliaries when necessary, and arranged to show all details, dimensions, and specifications, so the drawing could be used as a working drawing. Such a presentation is called an assembly-working drawing.

A drawing of a machine or structure might be for the purpose of emphasizing certain features of the object and is called a display-drawing. They are often special drawings and might not include the entire object. They are sometimes classified as assembly drawings.

Drawings which contain information for the erection of a machine or structure are called erection-drawings and are sometimes classified as assembly drawings. In the erection of a fabricated steel truss, subsections which were previously put together in the shop bear a number corresponding to a number on the erection drawings which show where each subsection fits into the truss as a unit.

Line drawings representing the outline of structures, wiring diagrams, piping diagrams, etc., are often classified as assembly drawings. Figure 59-XVII is a diagram-drawing of a Pratt truss and shows the stress diagram also.

Assembly drawings are sometimes executed in pictorial representations, Figures 12-XIV, 13-XIV, 14-XIV, and 19-XIV. They have decided advantages when used for catalogue cuts, to represent display features, and are useful also as nontechnical drawings. They are occasionally used as engineering drawings to represent small objects.

When detail drawings accompany an assembly drawing, each piece in the assembly should be numbered and the number used to identify the particular piece in the detail drawings and also in the bill of material.

3-XIV. Detail Drawings. A detail drawing, Figures 4-X, 5-X, 6-X, and 19-XIV, is a drawing (invariably in orthographic) of a single piece or part completely detailed by describing the size, shape, tolerance, finish, material, and quantity wanted. In addition to the required number of principal views, auxiliary views should be used and principal views sectioned when necessary. Conventional drawings of bolts, screws, shafts, (showing conventional breaks), springs, etc., should be used when possible. Difficult details, piping layouts, and the like, are sometimes shown in pictorial.

4-XIV. Special Drawings. There are numerous types of drawings made for special feature work such as display, erection, and diagram drawings--among others--which, when not used in connection with assembly drawings, are listed as special drawings. One type of diagram drawing is shown in Figure 17-XVII. Vector diagrams, graphs, charts, etc., are other forms of special drawings. See Ch. XVII.

5-XIV. To Make a Working Drawing. The student should review the Introductory, Chapter I. In this chapter it was pointed out that the fundamentals of drawing are: (1) accuracy, (2) speed, (3) neatness, and (4) style, and these were then explained. In addition to such fundamental factors, the following are given for the making of working drawings:

1. Preparation of the paper.
2. The title.
3. The scale.
4. Selection and arrangement of views.
5. Conventional lines, symbols, and idioms.

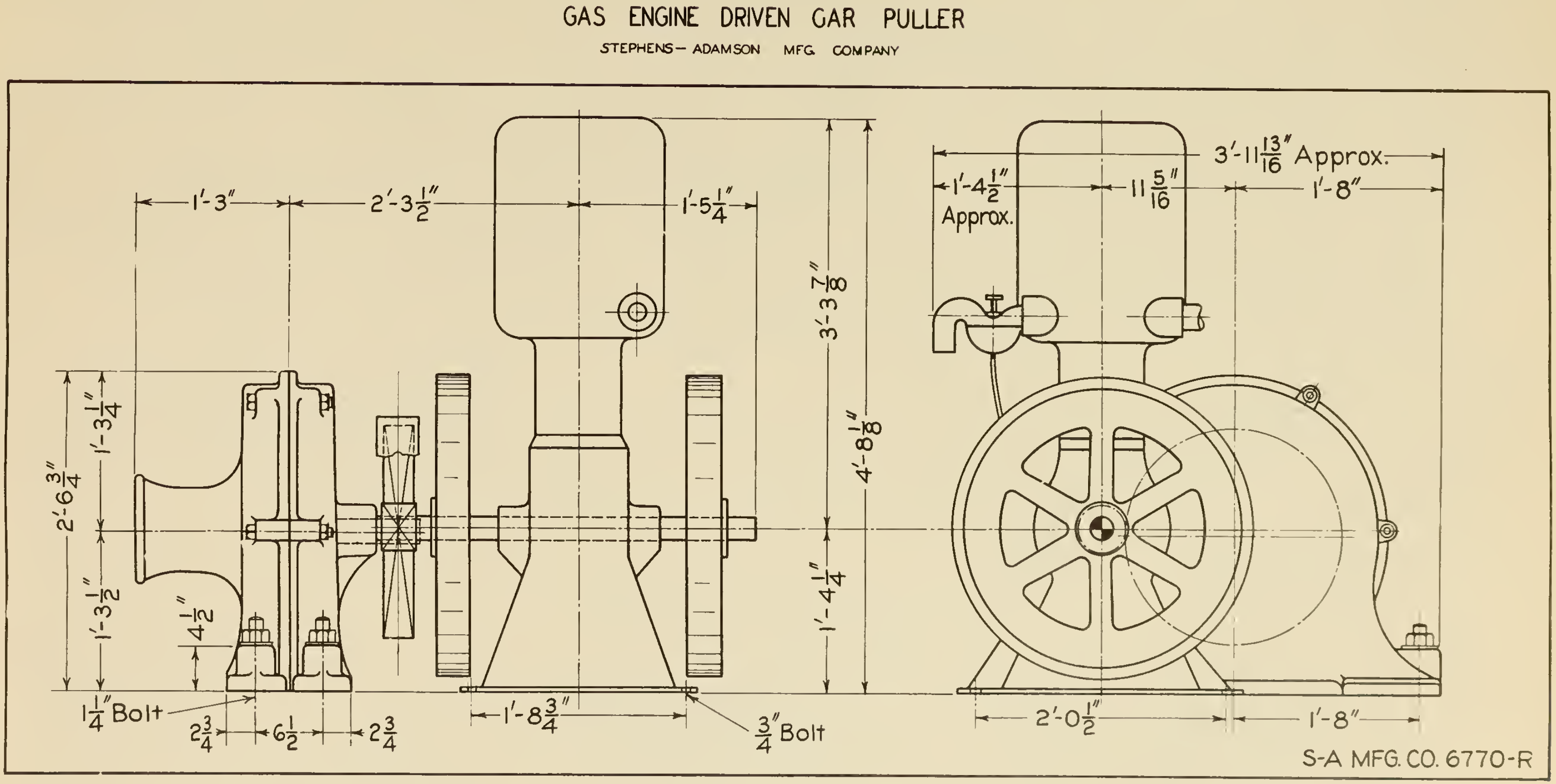


Figure 2-XIV. Two-View Assembly

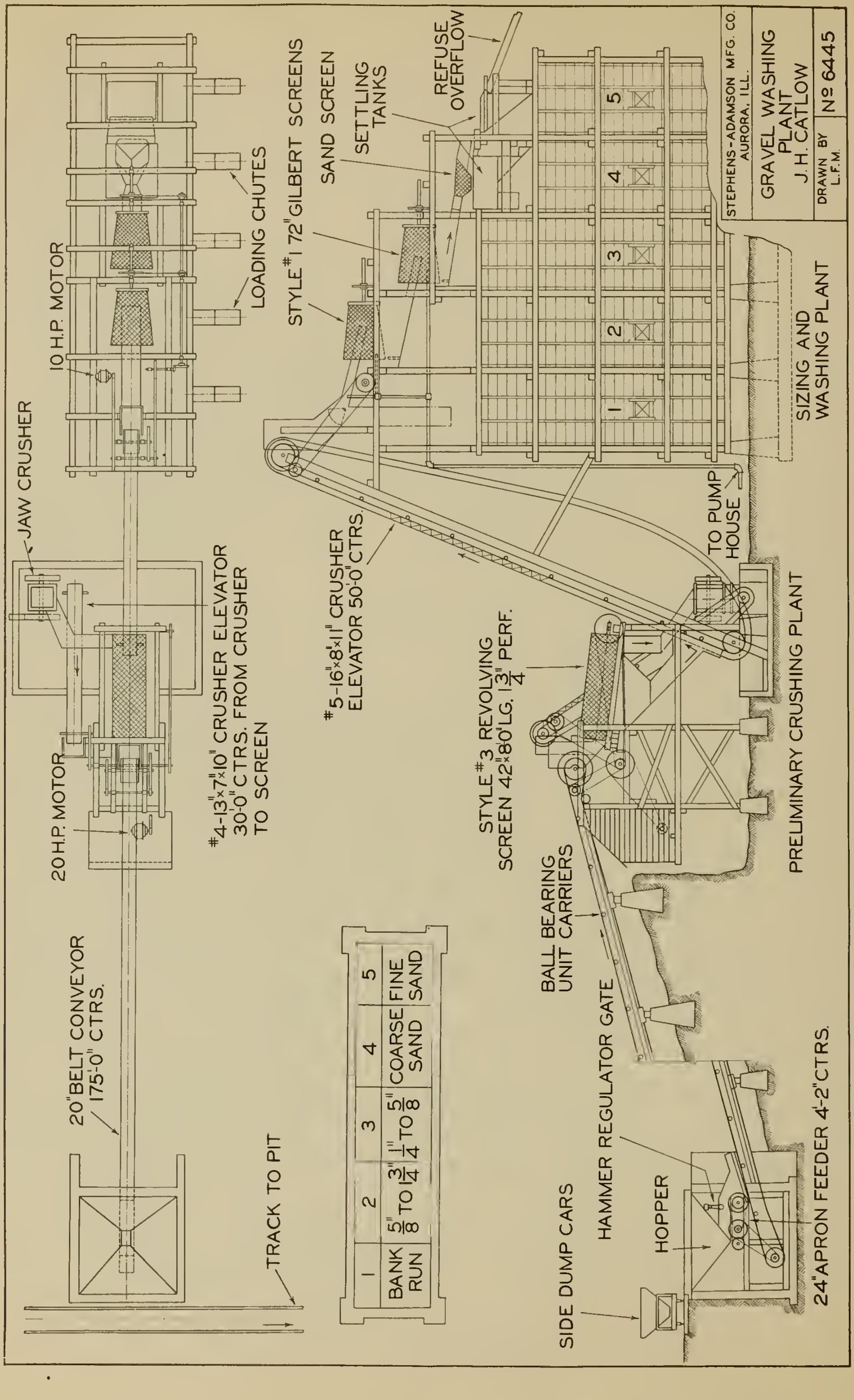

STEPHENS-ADAMSON MFG. CO.
AURORA, ILL.
GRAVEL WASHING PLANT
J.H. CATLOW
DRAWN BY L.F.M.
Nº 6445
JAW CRUSHER
10 H.P. MOTOR
LOADING CHUTES
#4-13"×7"×10" CRUSHER ELEVATOR 30'-0" CTRS. FROM CRUSHER TO SCREEN
20 H.P. MOTOR
20" BELT CONVEYOR 175'-0" CTRS.
TRACK TO PIT
1 BANK RUN
2 5/8" TO 1 3/4"
3 1/4" TO 5/8"
4 COARSE SAND
5 FINE SAND
STYLE #1 72" GILBERT SCREENS
SAND SCREEN
SETTLING TANKS
REFUSE OVERFLOW
1
2
3
4
5
#5-16"×8'×11" CRUSHER ELEVATOR 50'-0" CTRS.
TO PUMP HOUSE
SIZING AND WASHING PLANT
STYLE #3 REVOLVING SCREEN 42"×8'0" LG. 1 3/4" PERF.
PRELIMINARY CRUSHING PLANT
BALL BEARING UNIT CARRIERS
HAMMER REGULATOR GATE
HOPPER
SIDE DUMP CARS
24" APRON FEEDER 4'-2" CTRS.

Figure 3-XIV. Plant Assembly

6. Dimensioning.
7. Notes, legend, and bill of material.
8. To pencil a drawing.
9. To ink a drawing.
10. To trace a drawing.
11. To check and revise a drawing.

They are explained in the following articles.

6-XIV. Preparation of the Paper. In the commercial drawing offices, standard sheet sizes are maintained, and the size depends upon the amount of matter to be drawn upon the plate. A good quality of paper should always be used. If the drawing is to be inked, a white cold press paper should be used. Erasures can be made best on this kind of paper. If the drawing is to be finished in pencil or is to be done in pencil and then traced, a buff detail paper should be used. A buff paper is much easier on the eyes.

7-XIV. The Title. The different forms of titles, with illustrations, were presented in Chapter II, and title composition was discussed. The commercial companies often have the title ruling and some of the title matter printed on the sheet. If this is not done, the draftsman should lay out the title space to be sure there is room reserved for it. Numerous title illustrations are given in this chapter. A title should contain at least:

1. Name of manufacturer or engineering concern.
2. If for a specific job, the name of the purchaser of the machine or owner of the structure.
3. Date.
4. Scale.
5. Drawn by---.
6. Checked by ---, or approved by ---.

Such drafting room records as traced by ---, file numbers, authority for and date of revisions are often included in the title. The name of the part--if it is a detail of an individual piece--is sometimes given. If a set of drawings is being prepared, the total number of sheets and the individual sheet number should be given. Sheet number four in a set of twelve drawings should be labeled "Sheet 4 of 12."

8-XIV. The Scale. In Use and Care of Drawing Equipment, Chapter III, the scale and its application are described. The selection of the scale will depend upon the size of the object to be drawn and the space available for the drawing. A scale as large as possible should be used, especially for detail drawings, and the drawing space filled as nearly as possible.

9-XIV. Selection and Arrangement of Views. The object to be drawn should first be carefully studied, the minimum number and kind of views determined, and then a space for each view laid out on the plate. This procedure will assure the draftsman of no unnecessary crowding when the last drawings are put on the plate. An outline sketch of the plate will help materially in the choice and arrangement of views. In addition to the principal views, auxiliary views should be used and principal views sectioned when necessary. As far as practicable, the detail drawings of a machine, or piece of mechanism, should be placed on the drawing according to the relative positions of the various parts when assembled. Nuts and washers should be drawn on the bolt, or screw, or next to the threaded end of the fastener. The same scheme should be carried out in arranging the positions of pulleys and bearings with respect to a shaft, and the arrangement of a shaft with respect to a frame or housing. Promiscuous arrangement of views or of drawings of the individual parts should not be practiced. Conventional representations of fasteners, springs, etc., and conventional breaks should be employed when possible.

10-XIV. Conventional Lines, Symbols, and Breaks. Every line in a graphical representation has a meaning of its own. This meaning should be clearly brought out in order to avoid misinterpretation. Custom has fixed the convention for the visible outline, invisible outline, center line, cutting plane line, dimension line, etc., by specifying the character of the line (full, dotted, dash-dot, etc.) and the weight of the line (weight 1, weight 2, etc.) as outlined in Article 16-III, Figure 12-III. The contrast of lines is an important factor in the readability of a drawing.

Conventional drawings, such as the representation of fasteners, springs, etc., which have been referred to often, should be used when possible. Conventional breaks, materials in section, and other conventional symbols should be incorporated in a drawing whenever the occasion demands. Many of these conventions are listed in the Appendix.

The idioms of drawing as outlined in Section Drawing, Chapter VII, and the first part of this chapter, should be followed strictly. It is extremely important for the draftsman to know the conventions and idioms of his language and adhere to them.

11-XIV. Dimensioning. Dimensioning represents one of the divisions of drawing, i.e., size representation, as outlined in Dimensioning, Chapter X. The rules for dimensioning and the manner of placing dimensions

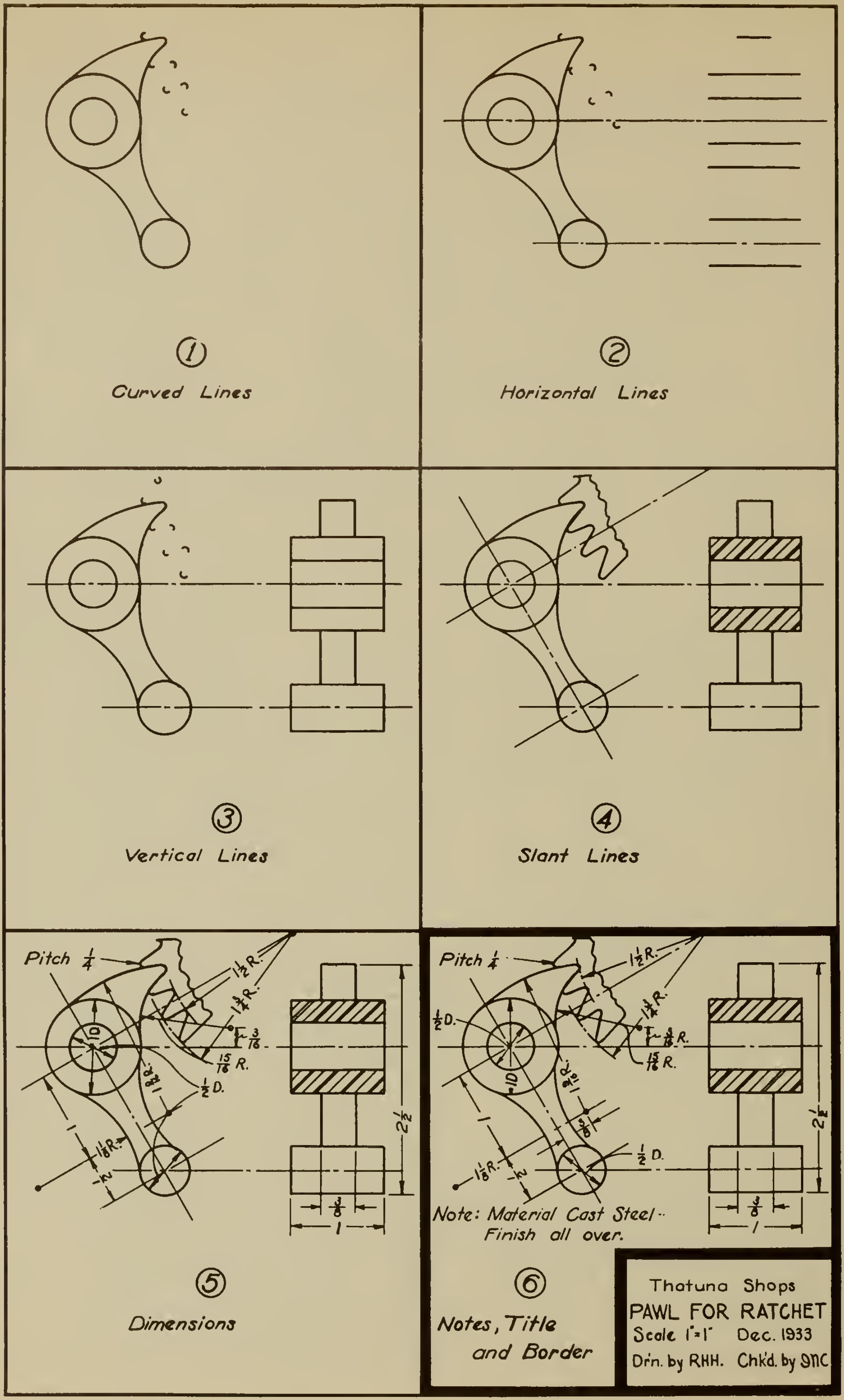


Figure 4-XIV. Order of Inking

should be strictly followed.

12-XIV. Notes, Legend, and Bill of Material. It becomes necessary from time to time to supplement the drawing proper with notes. This practice should not be followed, however, if the information can be conveyed by the drawing of views or by dimensioning. But certain information must be supplied by notes, such as instructions regarding certain shop practices, specifications for fasteners, and sometimes the instructions for finish or tolerance.

Often certain general information concerning the interpretation of the drawing or information covering the machine or part is put under the heading "Legend." This is also common practice in the preparation of maps, charts, graphs, etc. As a legend, the conventional lines and topographic symbols are often given, with other information.

When making detail drawings, it is customary to give the name of each part, the identification number of the piece (if an assembly view is drawn), the material to be used in constructing the article, and the quantity to be made (the number of each piece required). If there are only one or two detail drawings, this information is furnished as a note for each piece. If the object consists of a number of pieces, this information is usually furnished in a "bill of material", Figure 15-XIV, and is usually placed in the lower right-hand corner of the drawing. If the bill of material is exceptionally large, especially if it contains other information, it is often placed on a separate sheet.

13-XIV. To Pencil a Drawing. Emphasis should be laid on the penciling of a drawing. A great deal of time can be wasted in inking or tracing a drawing that has been poorly done in pencil.

After the size of sheet, scale, and the number and arrangement of views have been decided upon, the order of pencil work should be:

1. Block out the space for each view, title, and bill of materials.

2. Draw center lines as axes of symmetry, i.e., one center line in elevation drawings of cylinders, cones, etc., and two center lines for circles.

3. Begin work on all views of the same piece, starting with the front views (the characteristic lines of an object should be placed in the front view). Then work back and forth between views. The most prominent details should be drawn first and the least important ones drawn last.

4. Draw witness lines, dimension lines, and place dimensions.

5. Put on the notes. Letter the bill of material and the title.

6. Check the entire drawing.

14-XIV. To Ink a Drawing. The reader should turn to Use and Care of Drawing Equipment, Chapter III, and review the instructions for inking. In inking a drawing or when making a tracing of a drawing, the following order should be observed, as illustrated in Figure 4-XIV.

1. Ink all curved lines: (a) solid circles (largest ones first), (b) circular arcs, (c) dotted circles and arcs, and (d) irregular curves.

2. Ink all horizontal lines: (a) full lines, (b) dotted lines, and (c) center lines.

3. Ink all vertical lines: (a) full lines, (b) dotted lines, and (c) center lines.

4. Ink all slant lines: (a) full lines, (b) dotted lines, and (c) center lines.

5. Ink witness lines and dimension lines: (a) horizontal lines, (b) vertical lines, and (c) slant lines. Ink the arrowheads. Ink the dimensions.

6. Ink notes, title, and border.

7. Check your work.

15-XIV. To Trace a Drawing. The original drawing is seldom, if ever, used "on the job" or in the shop. Instead, the original drawing, after it has been finished in pencil, is traced in ink on tracing cloth, and a reproduction of the drawing made from the tracing. The reproduction is more commonly a blueprint. The blueprints are then used to work with. Tracings (or the original drawings) are sometimes made on a specially prepared transparent tracing paper. Tracings on paper should be made with a soft pencil, and prints of fair quality can then be made from the pencil tracings. Tracings on paper are temporary.

Tracing cloth, a high quality fabric, is transparent after it has been sized with a starch solution. The manufacturers recommend the glazed side of the cloth for inking. Most draftsmen, however, prefer the dull side, since it will take penciling. The traverse of a map or the skeleton of a drawing is often penciled on detail paper (the hard copy), a tracing made of the pencil layout, and the pencil work finished on the cloth. The inking is then completed. The cloth should be tacked down smoothly over the pencil drawing and its selvage removed. The selvage is that part of a roll of cloth on the extreme ends which contains a hard woven thread, usually red. Its length does not change readily with the moisture content of the air. On the contrary, tracing cloth will shrink or expand with atmospheric moisture. Therefore, the draftsman should keep moist hands and arms off the tracing. Also, a tracing of a view or object should not be allowed to stand overnight partially traced, if it is possible to avoid it.

The surface of the tracing cloth has a thin oil finish as a preservative. Before work is begun, the oil should be removed by rubbing the surface with a powder preparation, pounce, a talc powder, or blackboard eraser dust. The powder or chalk dust should be carefully wiped off the tracing. Pens should be well sharpened.

To insure sharp lines on the print, a heavy line should be used and a good black ink. Colored inks will give gray lines on the prints with the effect of suppressing those lines. A gray surface can be obtained by rubbing a soft pencil or a colored pencil on the dull side of the cloth or by putting a colored wash on either side of the cloth. A wash of diluted black India ink can be used effectively.

Erasures should be made as directed in Use and Care of Drawing Equipment, Chapter III. They should not be made with a razor blade or other sharp instrument.

16-XIV. To Check or Revise a Drawing. Some commercial offices employ checkers whose work it is to check drawings. The order of checking given below is also an efficient exercise for reading a drawing the first time. It often becomes necessary to revise a drawing. When this is done, the drawing is checked, the revisions are made, then rechecked, and the date of revision is indicated in the title. If possible, a complete new tracing should be made incorporating the revision and the old tracing kept as a record. If this is not practical, then two or three prints of the original tracing should be filed as a record.

When checking a drawing, the following order should be observed and corrections indicated with a soft or colored pencil:

1. Put yourself in the position of the person who is to use the drawing and see if the necessary information has been furnished him, furnished in a manner that is usable by him, and put on the drawing where he would expect to find it.

2. See that the necessary views are drawn, the unnecessary ones are omitted, and the correct shapes are represented.

3. Check the dimensions by scaling or by computations. Preserve all calculations. See that over-all dimensions and summation dimensions are given. Dimensions should be given so that workmen will not have to make additions or subtractions, as indicated in Dimensioning, Chapter X.

4. Check for tolerance. A tolerance that is too coarse is mechanically inefficient. A tolerance that is too fine is economically inefficient.

5. Check the finish specifications.

6. Check all moving parts for clearance. If necessary, lay out motion diagrams as a check.

7. Check all fasteners to see if the conventions are properly represented, if they are of standard sizes, and if the sheet metal, wire, and other gages are standard.

8. Check notes, title, and bill of material. See that the proper materials are specified and that the quantity required of each piece is correct.

9. Review your work.

17-XIV. The Reproduction of Drawings. The most common reproductions of drawings are: (1) blueprints, (2) ozalid prints, and (3) Vandyke prints. A short description of each is given below.

Blueprints. The surface of the paper is sensitized with a chemical compound that reacts in the presence of light. The tracing is placed against the sensitized surface with the inked side out (as it would normally be read). The two are put in a frame with a glass cover and exposed to the sun, or placed against a glass in a specially designed electric machine, with the tracing on the side next to the light. As the light rays do not penetrate the ink lines, no chemical reaction takes place underneath them, and the result is a white line. The light going through the transparent cloth causes a chemical reaction on the sensitized surface. After a proper period of exposure, the tracing is removed and the paper immersed in water. The chemical reaction ceases, and the result is a white line on a deep blue background, a negative print.

Objections to this process are: (1) water causes the paper to shrink and warp out of shape. Therefore, the drawings cannot be scaled, and scaled additions to the drawing cannot be made. (2) As it is a negative reproduction, it is hard on the eyes to work over blueprints except for very short periods of time.

Ozalid. The ozalid paper has a surface that is chemically sensitive to light and is exposed as described in the paragraph above on blueprints. The development (fixing process which stops the chemical action) is made in ammonia fumes (a gas) rather than in water. The result is a dark brown line on a light cream background, a positive print. The ozalid is fast replacing the blueprint for the following reasons: (1) Being developed in a gas, there is no shrinking of the paper, and the print can therefore be scaled. Scaled additions can be made to the drawing. (2) As it is a positive print, it is much easier on the eyes.

Vandyke. The Vandyke is a very thin sensitized paper. When exposed as described in the paragraph on blueprints, the result is a white line on a very dark brown (almost black) field. It is a negative tracing. The fixing process includes washing in water, then in hyposulphite of soda, and again in water. The negative is seldom used to work with. A positive print--which is preferred--may be obtained as follows: Place the inked side of the tracing next to the Vandyke paper. Expose and develop as explained above. With the negative tracing and a specially prepared paper, expose as described in the paragraph on blueprints. Develop in water. The result is a dark brown line on a light field, a positive print. If a blueprint paper had been used instead of the specially prepared paper described above, the result would have been a blue line on a light field, a positive print. Advantages: a positive print. Disadvantages: (1) higher costs, (2) shrinkage which causes a distorted scale. Scaled additions can, therefore, not be made to the drawing.

## EXERCISES

18-XIV. The student should choose his own scale, determine the problem space, select the number of views to be drawn, and make the arrangement of views to the best advantage. It is advisable for the student to make a preliminary sketch of the problem and submit it to the instructor for approval before work on the plate is begun.

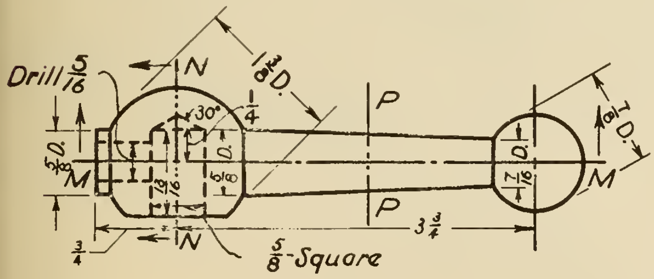


Figure 5-XIV. Socket Wrench--Clamping Lever

Due to the nature of the problem, the drawings as listed in this chapter do not always present the best choice and arrangement of views, and for this reason dimensions are not always arranged to the best advantage.

Some of the minor details and dimensions were purposely omitted from certain drawings of this chapter. As a problem in detail design, the student is expected to supply missing data.

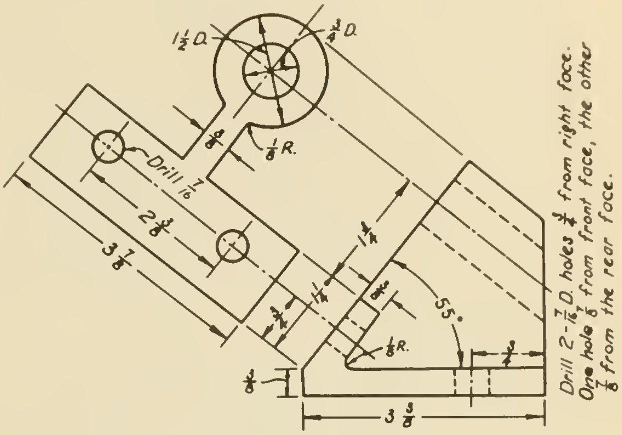

1 1/2 D.
3/4 D.
Drill 7/16
1/8 R.
55°
1/8 R.
3 3/8
Drill 2-7/16 D. holes 3/4 from right face.
One hole 7/8 from front face, the other
7/8 from the rear face.

Figure 6-XIV. Bearing Block

Group 1-XIV. Assembly Drawings

1-13. Make orthographic assembly drawings of the objects shown in the drawings of Figures 10-XIV, 11-XIV, 12-XIV, 13-XIV, 14-XIV, 15-XIV, 16-XIV, 19-XIV, 20-XIV, 11-XV, 27-XV, 28-XV, and 29-XV.

Group 2-XIV. Detailed Working Drawings

1-14. Make detailed working drawings of the objects shown in the drawings of Figures 5-XIV, 6-XIV, 7-XIV, 3-XVI, 4-XVI, 6-XIV, 16-VIII, 22-VIII, 23-VIII, 24-VIII, 11-VII, 14-VII, 15-VII, and 9-V.

15-19. Make detailed working drawings of the cast-iron brackets at joints $L_0$, $L_1$, $L_2$, $U_2$, and $U_3$, Figure 59-XVII. The bottom views, shown in the first four drawings, should be omitted and top views drawn instead.

Group 3-XIV. Assembly-working Drawings

1-16. Make assembly-working drawings of the objects shown in the drawings of Figures 8-XIV, 9-XIV, 10-XIV, 11-XIV, 12-XIV, 13-XIV, 14-XIV, 15-XIV, 16-XIV, 17-XIV, 18-XIV, 19-XIV, 11-XV, 27-XV, 28-XV, and 29-XV.

Group 4-XIV. Complete Set of Drawings

1-15. Make a complete set of drawings,

Figure 20-XIV, of an assigned object by making (1) a two-view orthographic assembly drawing located in the upper left-hand corner of the sheet; (2) followed by detailed working drawings of each individual piece located conveniently in the body of the sheet. (3) A heading should be placed across the top of the sheet, giving the name of the object. Any necessary notes and a bill of material should be placed in the lower right-hand corner. A title should be included. Each piece should be given a number which would identify the article in the assembly drawings and serve as a title for the detail drawings of the part, and should be placed opposite the name of the piece in the bill of material. (4) A tracing of the drawings should be made. Objects to be drawn: Figures 8-XIV, 9-XIV, 10-XIV, 11-XIV, 12-XIV, 13-XIV, 14-XIV, 15-XIV, 16-XIV, 17-XIV, 18-XIV, 19-XIV, 11-XV, 17-VIII, and 18-VIII.

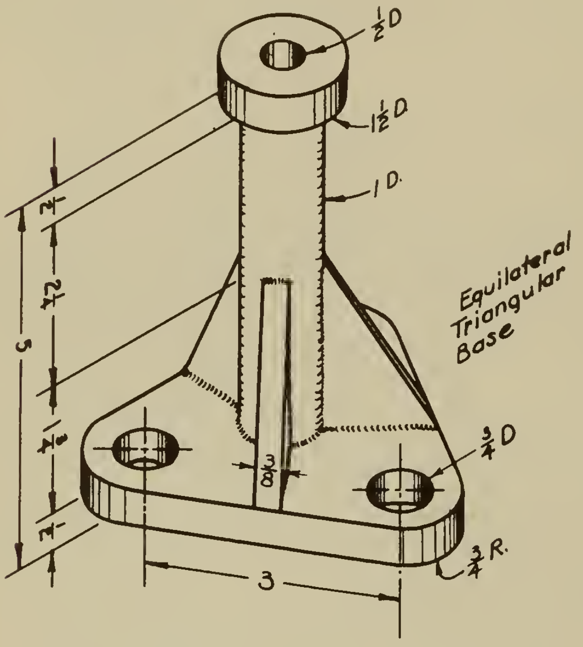


Figure 7-XIV. Stem Support

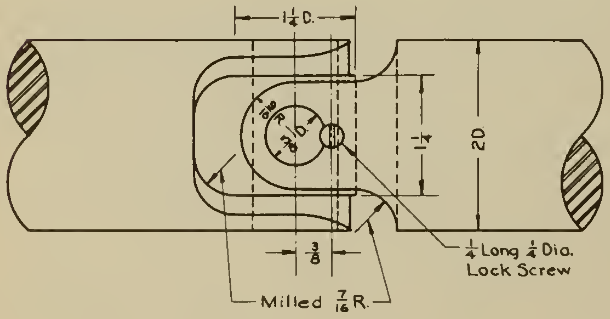
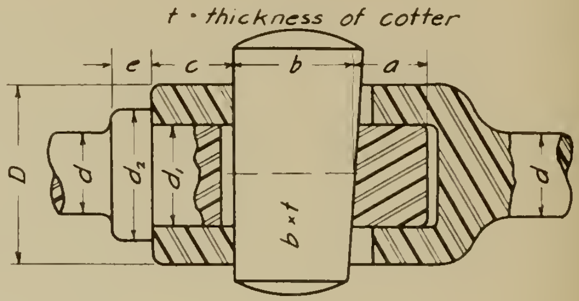


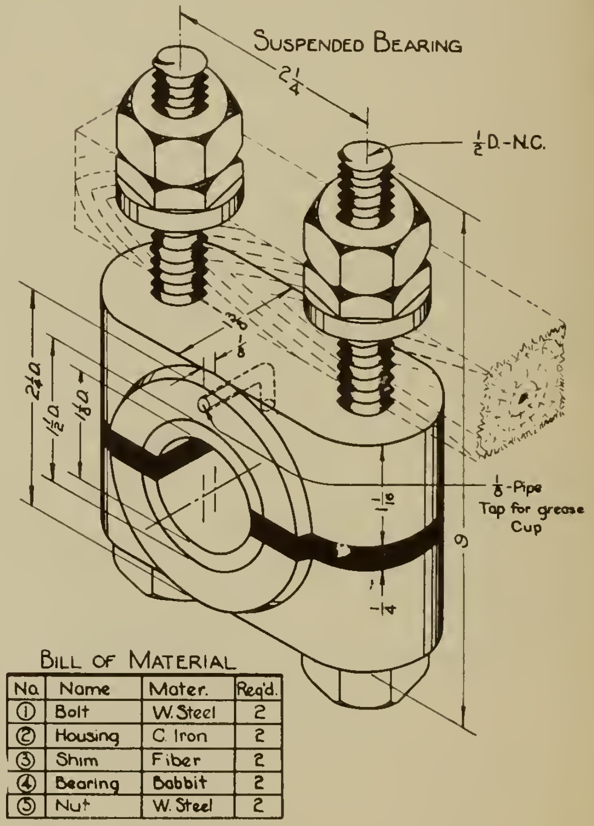
Figure 8-XIV. Universal Joint



a = 0.39d
D = 1.80d
$d_1$ = 1.28d
$d_2$ = 1.50d

b = 1.28d
c = 0.88d
e = 0.25d
t = 0.38d

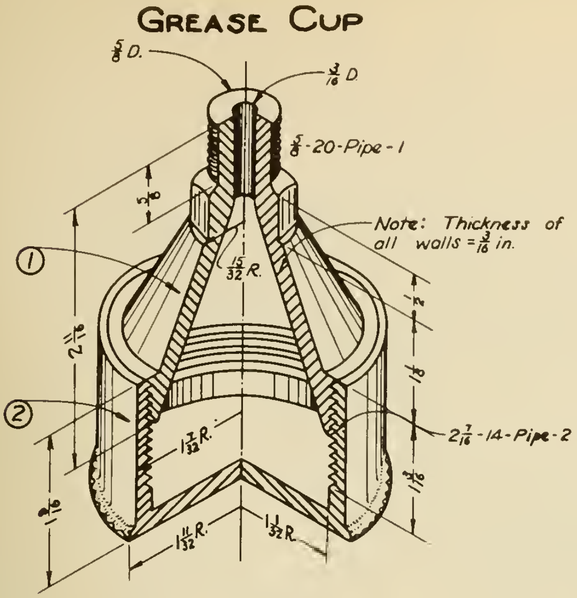
Figure 9-XIV. Cotter Joint



BILL OF MATERIAL

| No. | Name | Mater. | Req'd. |
|---|---|---|---|
| ① | Bolt | W. Steel | 2 |
| ② | Housing | C. Iron | 2 |
| ③ | Shim | Fiber | 2 |
| ④ | Bearing | Babbit | 2 |
| ⑤ | Nut | W. Steel | 2 |

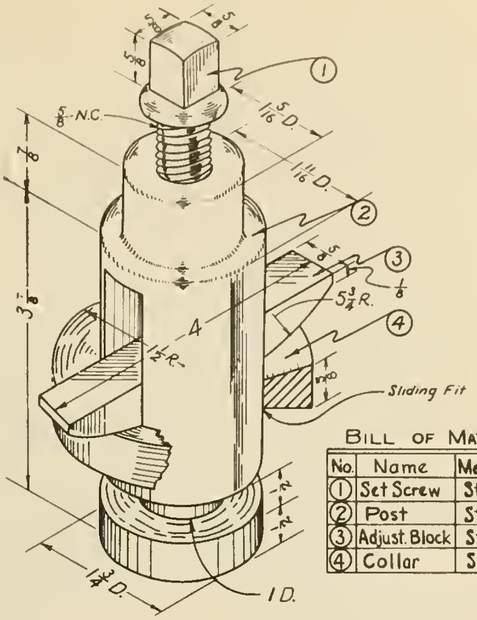
Figure 10-XIV. Suspended Bearing



BILL OF MATERIAL

| No. | Name | MATER. | Req'd |
|---|---|---|---|
| ① | Cup | Iron | 1 |
| ② | Cap | Iron | 1 |

Figure 11-XIV. Grease Cup



BILL OF MATERIAL

| No. | Name | Material | Req'd |
|---|---|---|---|
| ① | Set Screw | Steel | 1 |
| ② | Post | Steel | 1 |
| ③ | Adjust. Block | Steel | 1 |
| ④ | Collar | Steel | 1 |

Figure 12-XIV. Tool Post

BILL OF MATERIAL

| No | Name | Material | Quan |
|---|---|---|---|
| ① | Eccentric | Cast Steel | 1 |
| ② | Upper Strap | " " | 1 |
| ③ | Lower Strap | " " | 1 |
| ④ | Bolts & Nuts | " " | 2 |

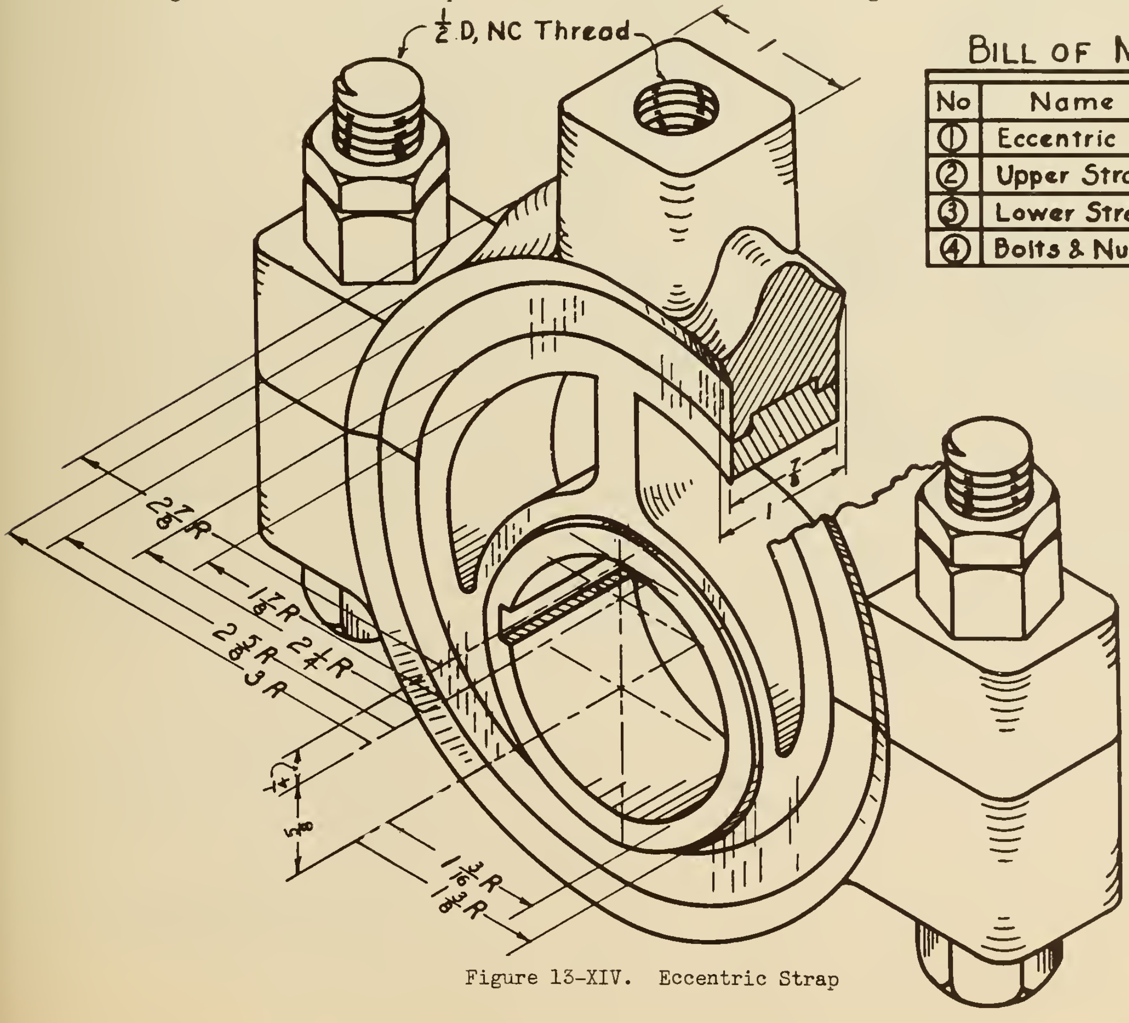
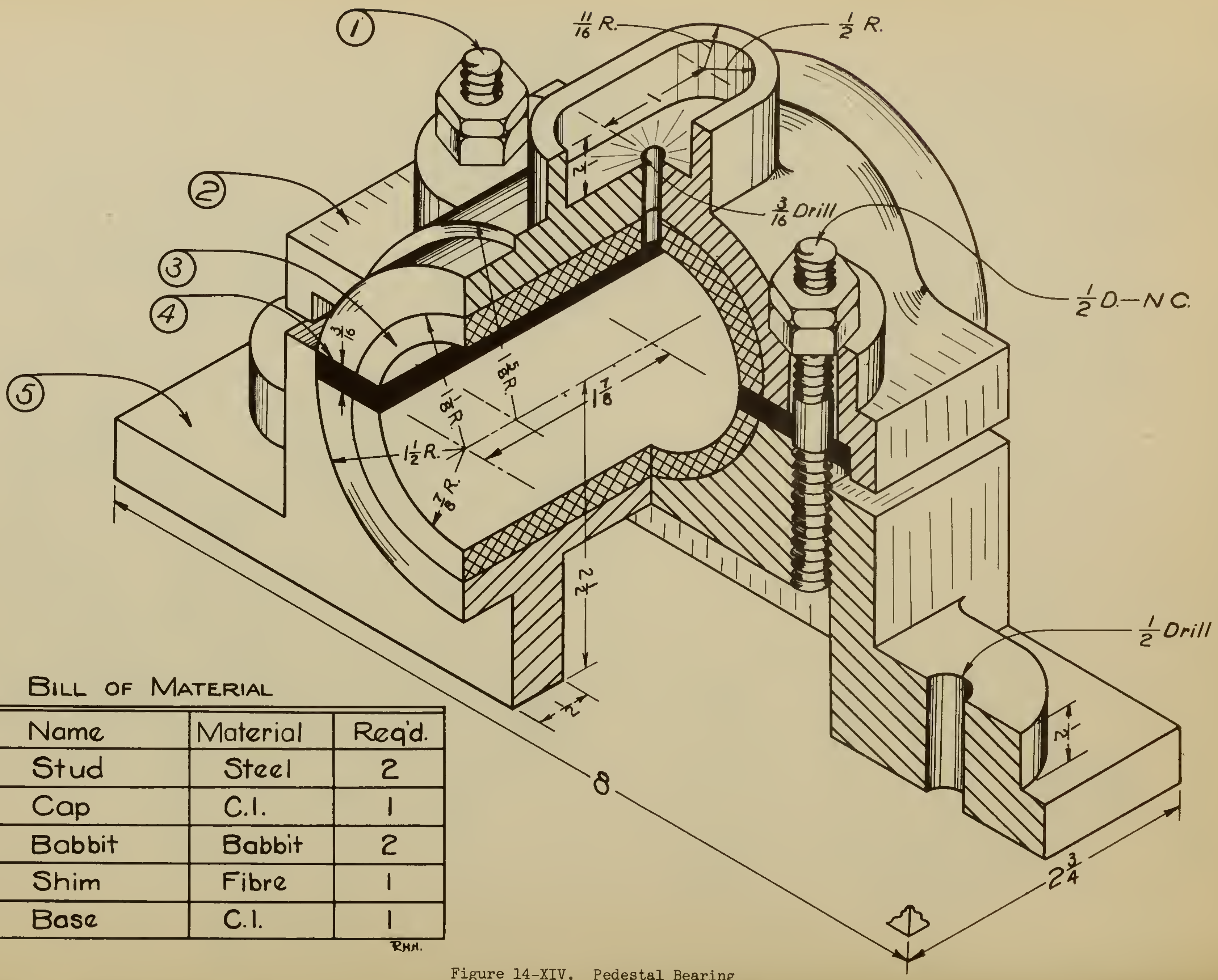


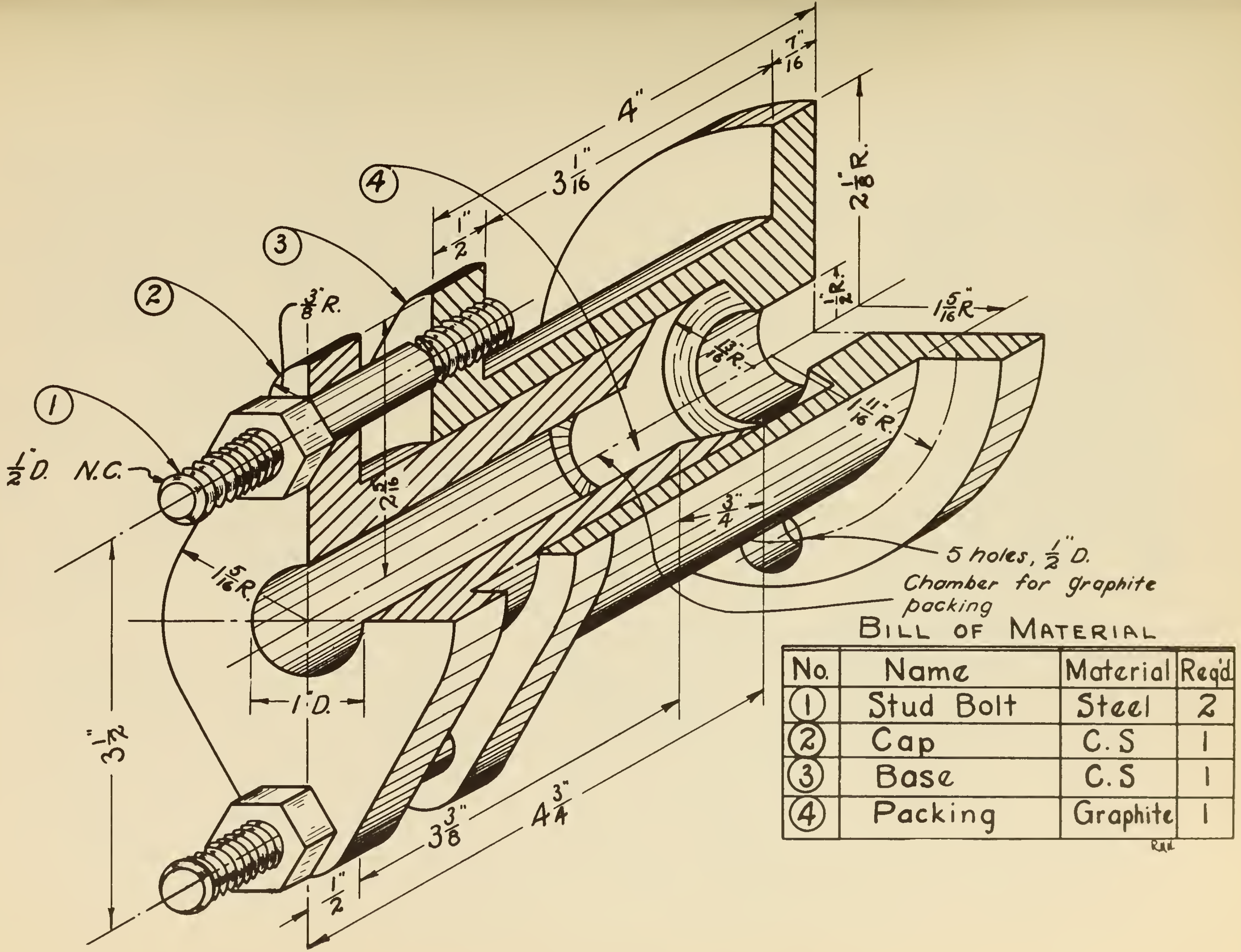
Figure 13-XIV. Eccentric Strap



BILL OF MATERIAL

| No. | Name | Material | Req'd. |
|---|---|---|---|
| ① | Stud | Steel | 2 |
| ② | Cap | C.I. | 1 |
| ③ | Babbit | Babbit | 2 |
| ④ | Shim | Fibre | 1 |
| ⑤ | Base | C.I. | 1 |

Figure 14-XIV. Pedestal Bearing



BILL OF MATERIAL

| No. | Name | Material | Req'd |
|---|---|---|---|
| ① | Stud Bolt | Steel | 2 |
| ② | Cap | C.S | 1 |
| ③ | Base | C.S | 1 |
| ④ | Packing | Graphite | 1 |

Figure 15-XIV. Packing Gland

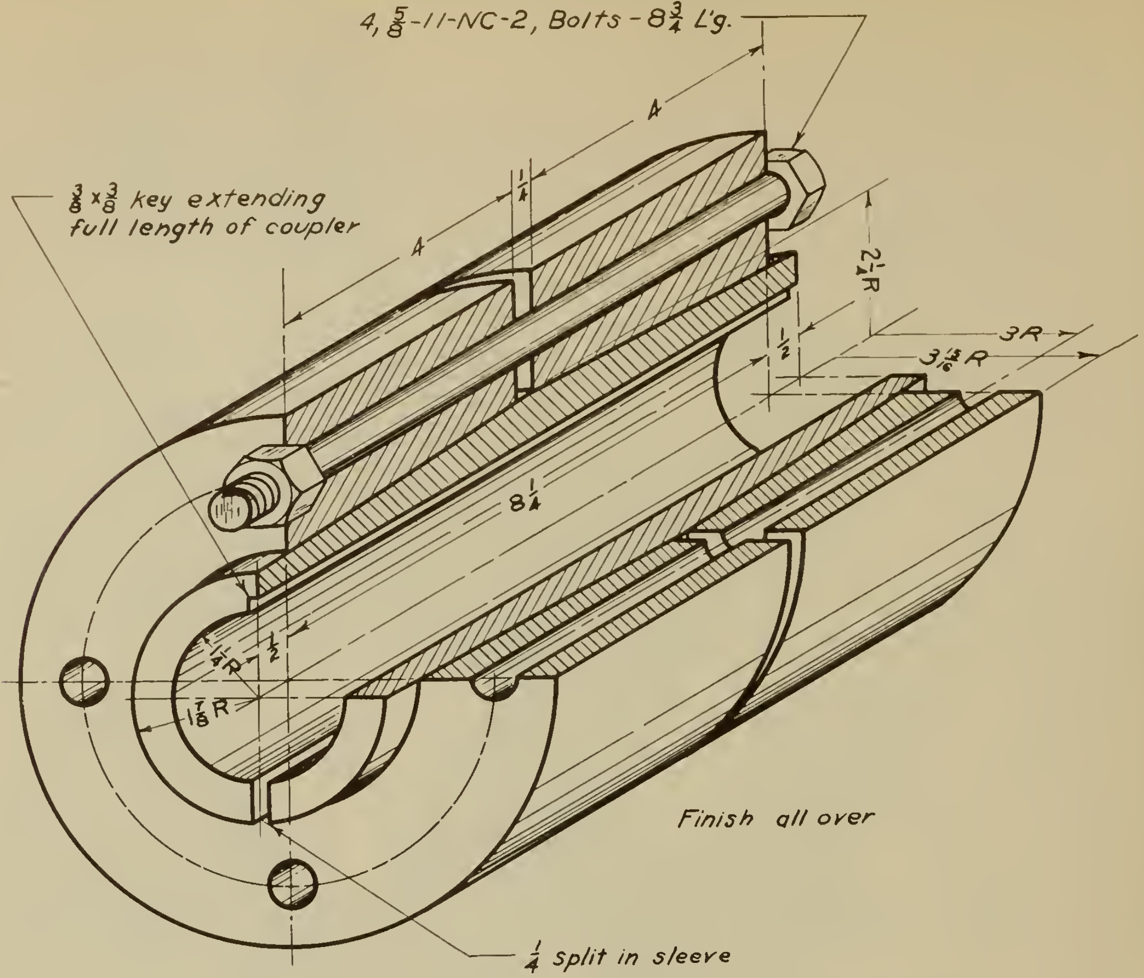

4, 5/8-11-NC-2, Bolts - 8 3/4 L'g.
A
1/4
A
3/8 x 3/8 key extending full length of coupler
2 1/4 R
1/2
3R
3 13/16 R
8 1/4
1/4 R
1/2
1 7/8 R
Finish all over
1/4 split in sleeve

Figure 16-XIV. Cone Coupling

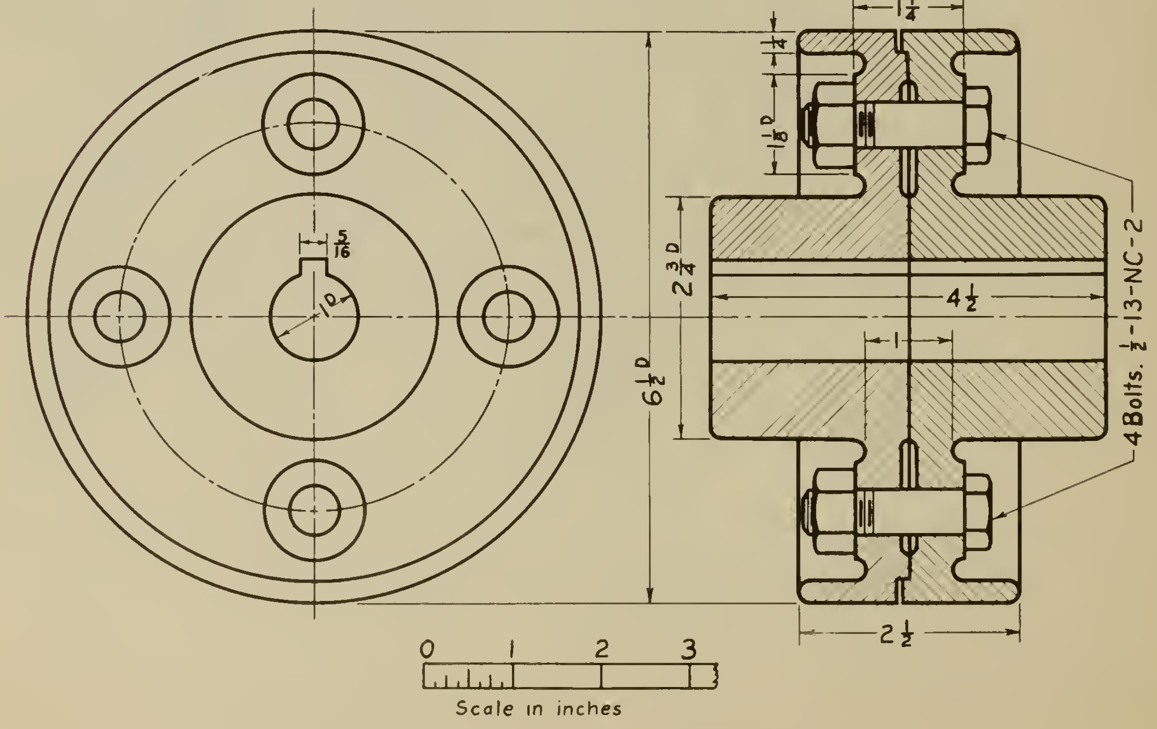


Figure 17-XIV. Flange Coupling

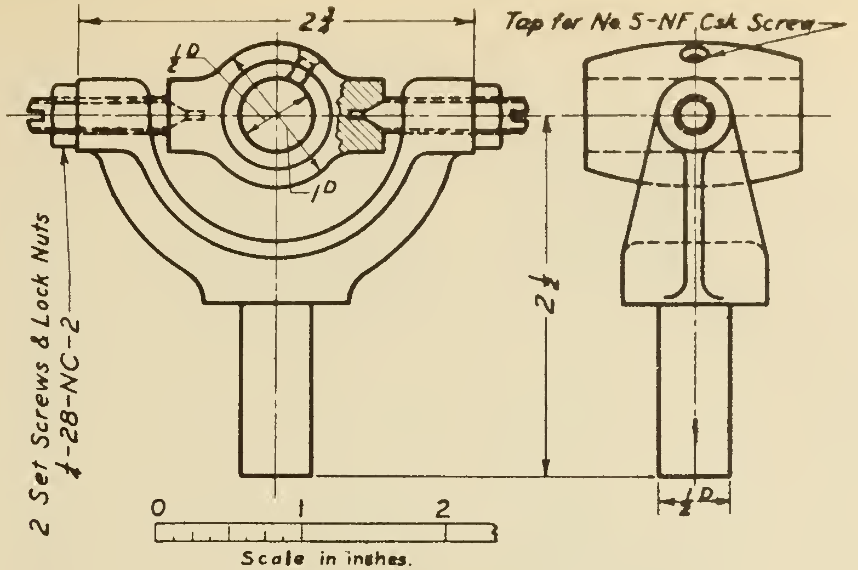


Figure 18-XIV. Adjusting Yoke

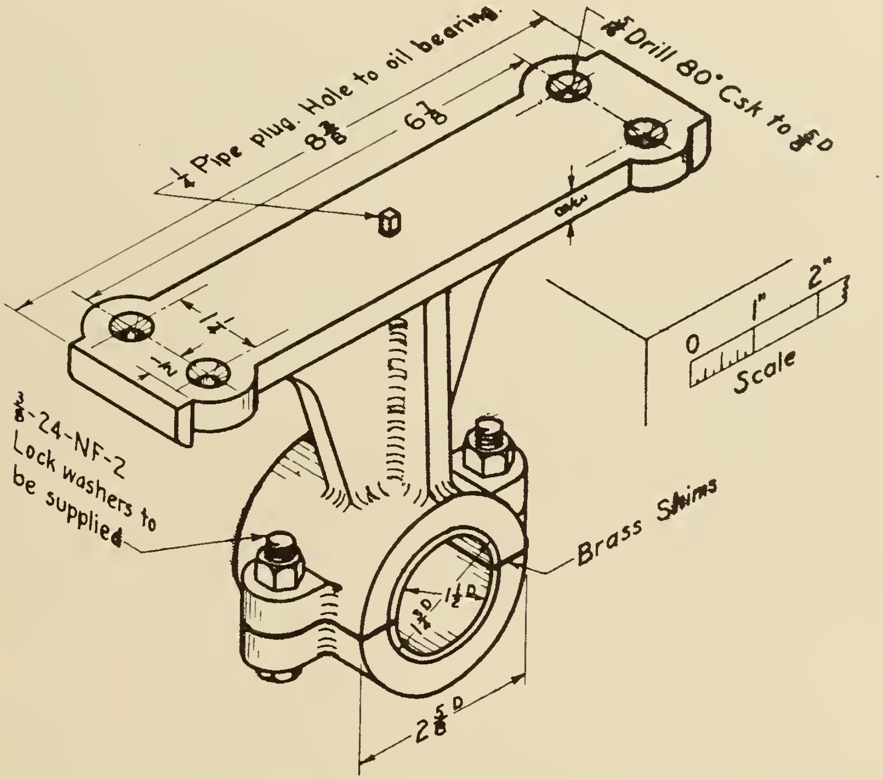
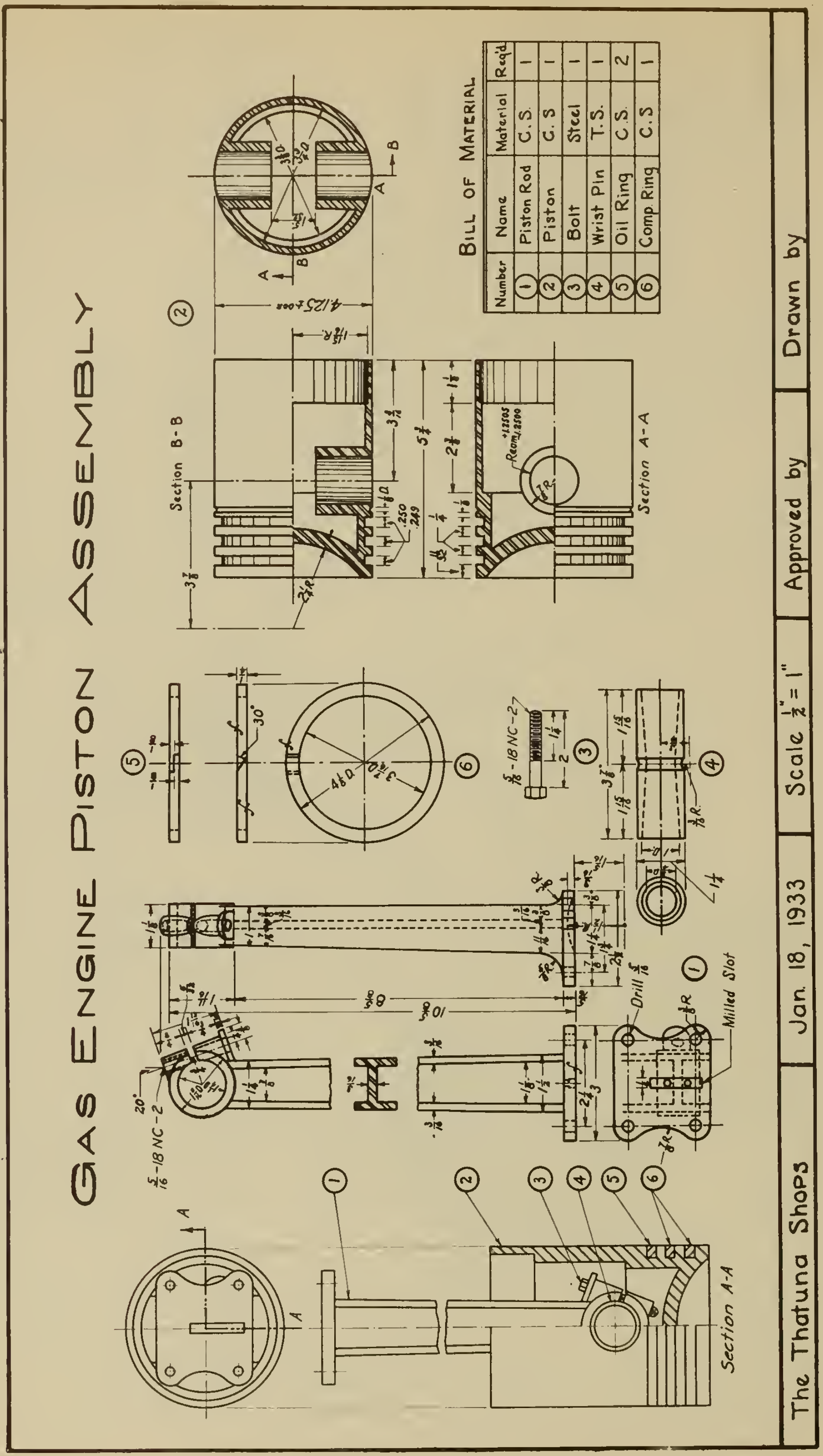


Figure 19-XIV. Hanger Bearing



BILL OF MATERIAL

| Number | Name | Material | Req'd |
|---|---|---|---|
| ① | Piston Rod | C.S. | 1 |
| ② | Piston | C.S | 1 |
| ③ | Bolt | Steel | 1 |
| ④ | Wrist Pin | T.S. | 1 |
| ⑤ | Oil Ring | C.S. | 2 |
| ⑥ | Comp. Ring | C.S | 1 |

Figure 20-XIV. Gas Engine Piston Assembly

# CHAPTER XV

## PICTORIAL DRAWING

1-XV. The engineer uses multiview drawings for accurate representation of objects, Figure 6-V (page 54), since he is primarily interested in representing the true size and shape of an object. Monoview representations (pictorial drawings) are used extensively for special feature work, such as assembly drawings, patent office drawings, difficult layouts or detailing, piping plans, and certain illustrations--such as catalogue cuts--for people who are not technically trained. Before proceeding further, the reader should review Chapter V, Theory of Drawing, which is the foundation for this chapter.

A drawing which represents the three rectangular dimensions in one view is called a pictorial. It is easily readable and conveys a definite meaning to the average person because (1) the three rectangular dimensions are represented, (2) the light and shadow on it tell something of the configuration of the object, (3) when looked at with both eyes, there is a stereoscopic effect which aids in judging shapes, sizes, and dimensions. In the practical application, however, the third factor is not considered, since an object is drawn as if seen with one eye. Only the artist uses the true representation of shades and shadows. The engineer uses line shading --a conventional representation of shade--and omits shadows in his axonometric and oblique drawings. Usually, the engineer deals with outline representation only.

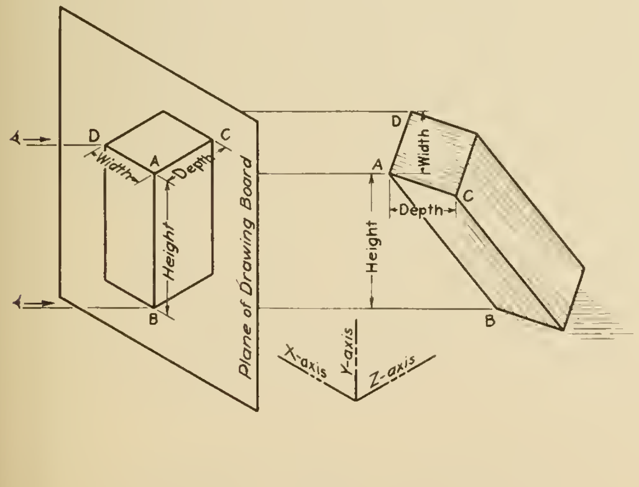


Figure 1-XV. Axonometric Representation

### Axonometric Drawing

2-XV. Theory of Axonometric Drawing. Axonometric is a form of orthographic drawing, Figure 1-XV, in which the three coordinate axes are represented in one view. It is therefore a pictorial representation, Figure 2-XV. The cube is first placed in simple position, position I. It is next rotated about a vertical axis through an angle less than 90 degrees. Two axes of the cube, AB and AD, are foreshortened (in the front view), position II. From position II the cube is tilted forward through an angle less than 90 degrees. In performing this operation, the right side view of II is transferred to III and used as a right side view after it has been rotated to the left about an axis perpendicular to the profile. The front view of III is obtained by drawing vertically downward from the front views of II. The three axes of the cube, AB, AC, and AD will appear foreshortened in the front view, which is the axonometric represented in position IV.

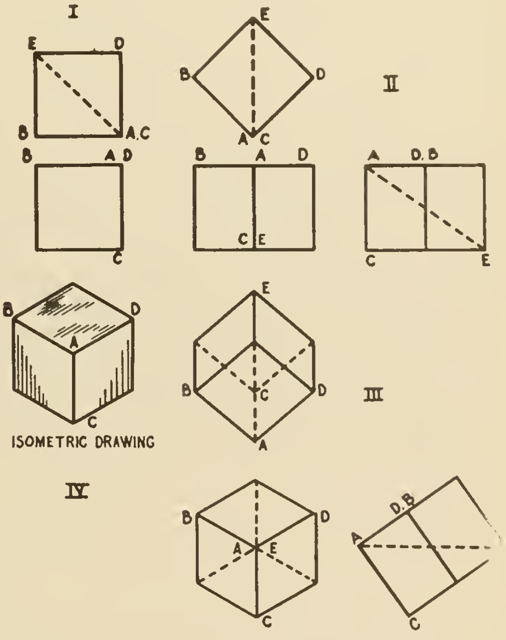


Figure 2-XV. Theory of Axonometric Drawing

It can be seen that an infinite number of axonometric drawings can thus be secured. However, only a few are in use, the more common forms being (1) isometric (the one shown in Figure 2-XV), (2) dimetric, and (3) trimetric, as explained in succeeding articles.

3-XV. Isometric. If the cube in I, Figure 2-XV, were revolved about a vertical axis through 45 degrees, as shown in II, and then revolved from position II about an axis perpendicular to the profile until the body diagonal AE became horizontal in the profile of position III, the front view of III would be a true isometric (equality of measure) drawing. The three isometric axes, AB, AC, and AD, will be foreshortened an equal amount. That is, the isometric axes makes equal angles with a frontal plane. Any line parallel to an isometric axis is called an isometric line. Lines not parallel to isometric axes are called nonisometric lines. The top face of the cube has a slope of 35°-16" (approximately) with the horizontal. In the true isometric drawing, isometric lines will be foreshortened approximately 0.81 of their lengths. An isometric scale could then be made as illustrated in Figure 3-XV and used to make the theoretically correct drawings instead of going through the various steps of revolving the object, as illustrated in Figure 2-XV. Instead of actually revolving the object, as was done in this case, the same results could have been obtained by taking an auxiliary view looking in the direction of the body diagonal AE, position I.

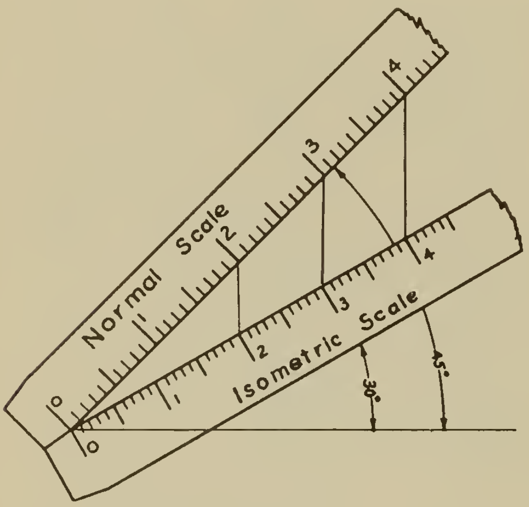


Figure 3-XV. Isometric Scale

The accurate representation of the isometric just described is often called the "isometric projection."

The theory of making isometric drawings is violated in practice. The foreshortening of lines mentioned above is disregarded, and full lengths are laid off on all isometric lines. This gives a figure with the proper shape but slightly larger than the theoretical drawing. Since most of the objects so drawn are relatively small, the discrepancy will, as a rule, not be excessive. The advantage of measuring lines directly will effect a material saving in time and will be a great convenience. This variation is sometimes called "isometric drawing."

To Make an Isometric Drawing: First, determine the position of the isometric axes, Figure 10-XV, and then sketch the axes in the upper left-hand corner of the drawing space (they are to be erased afterward). The axes will be 120 degrees apart. If a normal position is selected, one axis will be vertical. If the object is rectangular, as in Figure 4-XV, place one corner at A and draw three lines through this point parallel to the axes just sketched. You may consider lines AB, AC, and AD as isometric axes. On these three lines lay off the rectangular dimensions height, width, and depth, using full measurements. Complete the object by drawing other lines parallel to the axes and by laying off measurements on lines parallel to the axes. The direction of the pictorial axes should always be kept in mind. It will be advantageous, therefore, to draw these axes first and in a separate position and observe them from time to time during the making of the drawing. Hidden lines are omitted unless they are necessary for clearness.

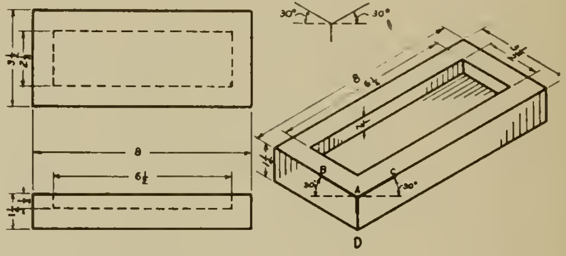


Figure 4-XV. To Make an Isometric Drawing

4-XV. Nonisometric Lines. As previously stated, lines not parallel to the axes are nonisometric and are not shown in true length. To locate these lines, the two extreme points are determined and then connected. The lines of the hexagonal bases of the prism in Figure 5-XV (A) are nonisometric.

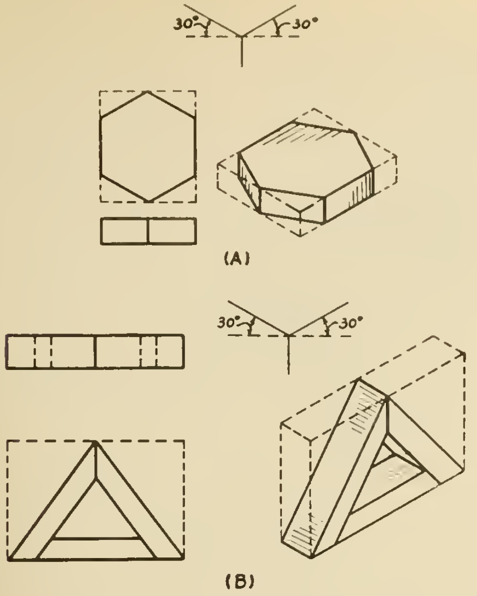


Figure 5-XV. Box Construction

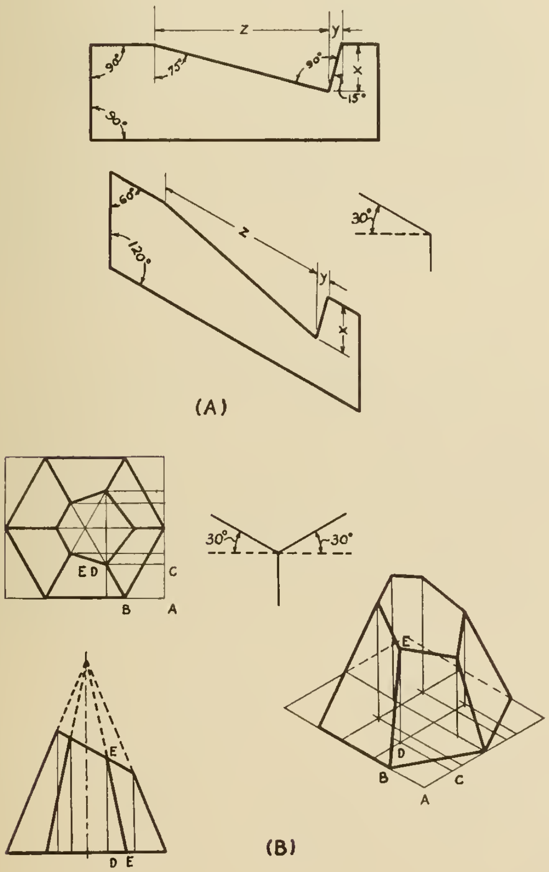


Figure 6-XV. Offset Construction

Measurements are taken from the orthographic at the left, along the dotted rectangle, and are transferred to the dotted rectangle in the isometric. After the extreme ends of the lines are thus determined, the points are connected, locating the lines. Nonisometric lines in Figure 5-XV(B) are similarly located. The method just described is known as box construction and can be used only in drawing the simpler objects. The method of drawing angles in isometric is illustrated in Figure 6-XV (A). Again dimensions are taken from the orthographic and transferred to the pictorial as indicated, making measurements on lines parallel to the pictorial axes. The axes should first be drawn.

When representing the more complicated objects, the offset construction method is used, Figure 6-XV (B). Here, perpendiculars are dropped from each point to a reference plane. The coordinates of points so located are taken from the orthographic and transferred to the isometric. To locate line BE: Point B lies in the reference plane ABC. If A is taken as the origin of coordinates, the coordinate for B is distance AB. E is a point in space, therefore, it will take three coordinates to locate the point. They are distances AC, CD, and DE, taken from the orthographic and laid off in the pictorial on lines parallel to the isometric axes. Again, the isometric axis should first be drawn as a reference.

5-XV. Isometric Curves. It is obvious that any curved line, when drawn in isometric, will be a nonisometric line. In order to draw isometric curves, a series of points can first be located on the orthographic drawing and then transferred to the isometric Figure 7-XV, making measurements on the respective coordinate lines. Other nonisometric figures, such as an octagon, can be drawn by this method, as illustrated in Figure 8-XV (A), on page 182. The same object could have been represented by first drawing the isometric circle (an ellipse), center at O, Figure 8-XV (B), and then locating the eight points of the octagon in the proper places on the circumference of the isometric circle.

Four Center Approximation. As just indicated, an isometric circle is an ellipse. It is usually drawn by the four center approximation, Figure 8-XV (C). The ellipse is approximated by four circular arcs but is different from the one used in Figure 15-IV (page 40). The center lines shown in Figure 8-XV (C) are isometric lines and are conjugate diameters of the ellipse, Figure 14-IV (page 40). The major axis of the four center

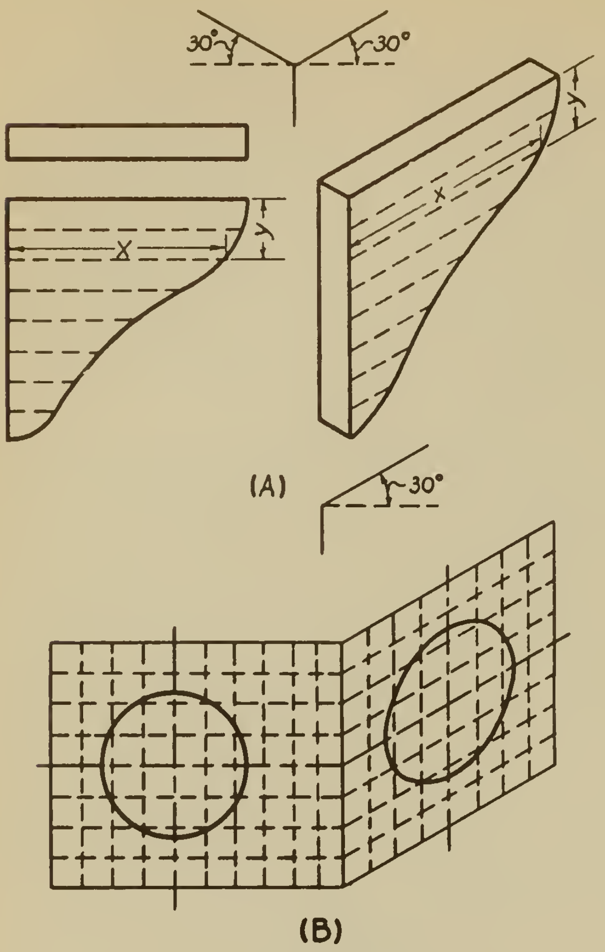


Figure 7-XV. Curve Construction

ellipse is greater than the diameter of the circle, which is a discrepancy. The ellipse of Figure 7-XV (B) is a true representation.

To Draw an Ellipse by the Four Center Approximation. Draw the isometric axes. Determine what isometric plane (face of the cube) you are working in, Figure 8-XV (C). Locate point O, the center of the ellipse (isometric circle), in the proper plane. Through O draw two center lines (conjugates of the ellipse) parallel to the two corresponding axes. On these center lines lay off from O the radius of the circle, taken from the orthographic, thus locating points, A, B, C, and D. Through these points construct a parallelogram with sides parallel to the respective pictorial axes. The ellipse will be tangent to the parallelogram at points A, B, C, and D. At these points draw lines making angles of 90 degrees with the sides of the parallelogram. These perpendiculars will intersect at the centers of the four circular arcs. Draw the arcs with radii as indicated.

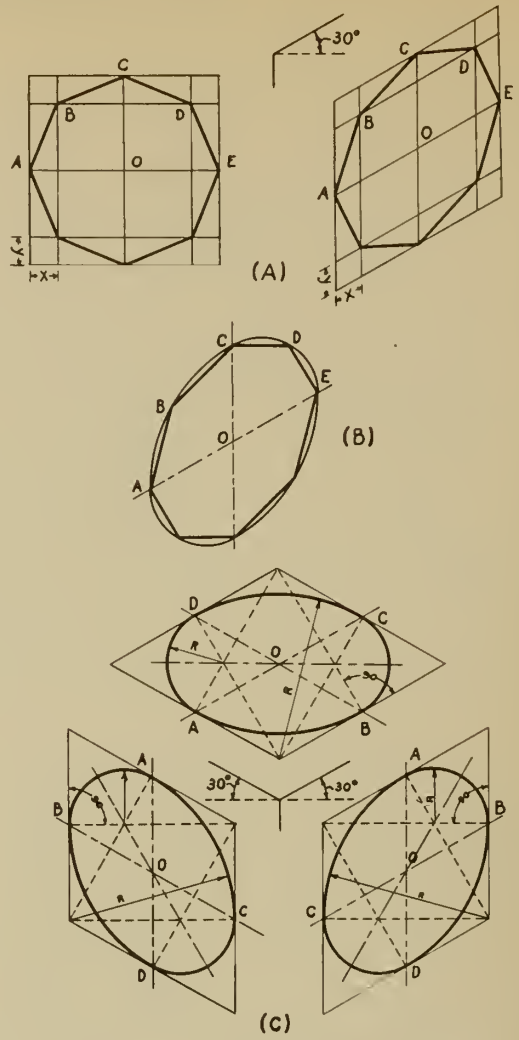
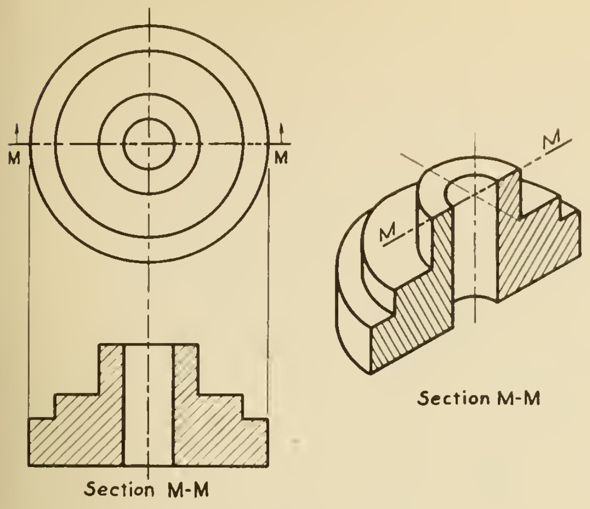


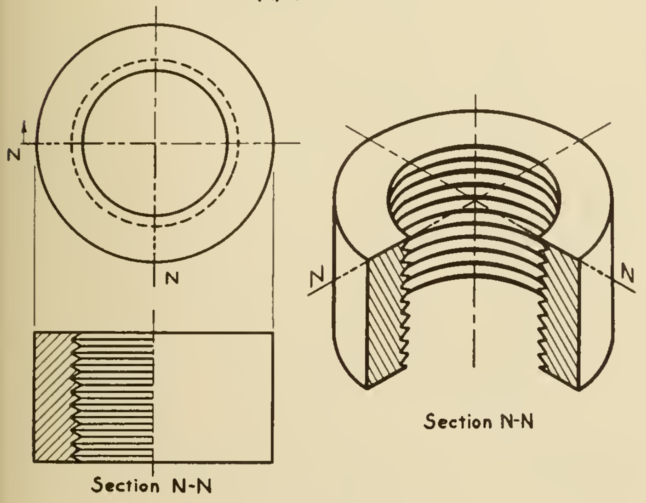
Figure 8-XV. Four Center Approximation

6-XV. Isometric Sections. It sometimes becomes necessary to cut sections in isometrics (since dotted lines are usually omitted) in order to show the interior detailing of an object. Half sections or full sections are usually employed, Figure 9-XV, although broken sections may be used to good advantage at times, Figures 12-XIV and 13-XIV. Occasionally a few dotted lines are necessary. Isometric planes are used as cutting planes. Section lining is done in a manner which will give the best effect. In making a half section it would be best to draw the outline of the entire object first and then cut out the front quarter. To make a full section the cut face should be drawn first and that part of the object beyond the cutting plane added last. The cutting plane lines M-M, N-N, etc., as a rule, are not labeled on the pictorial drawing. They are labeled here for illustrative purposes.

7-XV. Position of Isometric Axes. The



(A) Full Section



(B) Half Section

Figure 9-XV. Isometric Sections

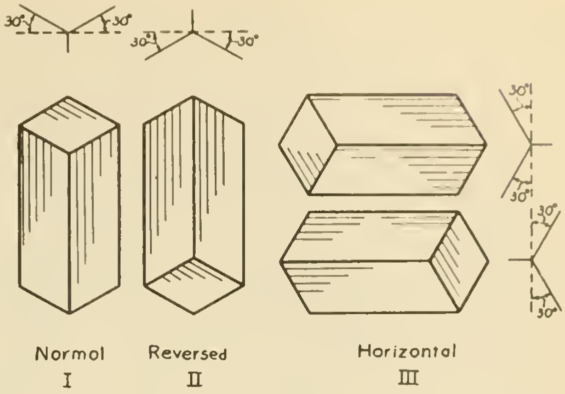


Figure 10-XV. Position of Isometric Axes

isometric axes are normally located with the longest one vertical, as indicated in Figure 10-XV. However, the object should be drawn when placed in its natural position, in which case the longest axis is sometimes horizontal with the other two axes placed as shown. The observer is often placed in the position of looking at an object from underneath. In such a representation the axes of the drawing should be reversed and placed as shown. Figure 11-XV is a typical illustration of an isometric drawing.

8-XV. Dimetric. If the reference cube of Figure 2-XV had been revolved so that two of the axes made equal angles with a frontal plane, position III, and the third axis made a different angle, the drawing of position IV would be a true dimetric (two measures). The cube might have been revolved into any number of positions where two of the axes would have been foreshortened an equal amount, and the resulting system would still have been a dimetric development. A system as described above is sometimes called a "dimetric projection" but is not desirable from the point of application. It is convenient to have the foreshortening ratio of the three axes conform to common scale sizes. If the axes were foreshortened on a ratio of 1:1:1/2, a great convenience would be effected. In order to obtain that ratio, the tangents of the desired angles would be 1/8 and 7/8 and would make angles of approximately 7 degrees and 41 degrees, as indicated in Figure 12-XV, position II.

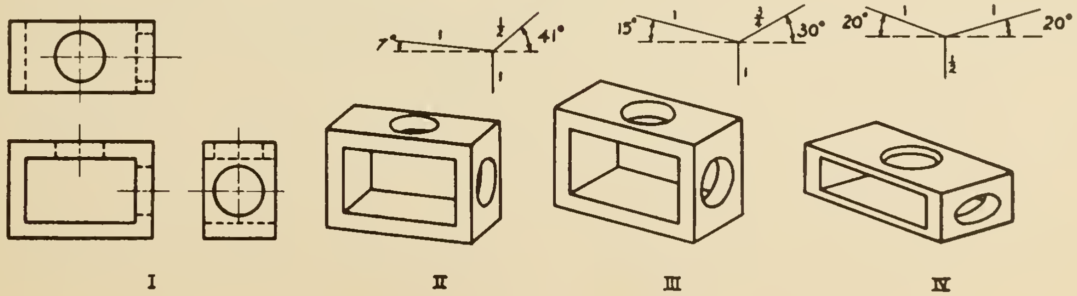


Figure 12-XV. Dimetric Drawings

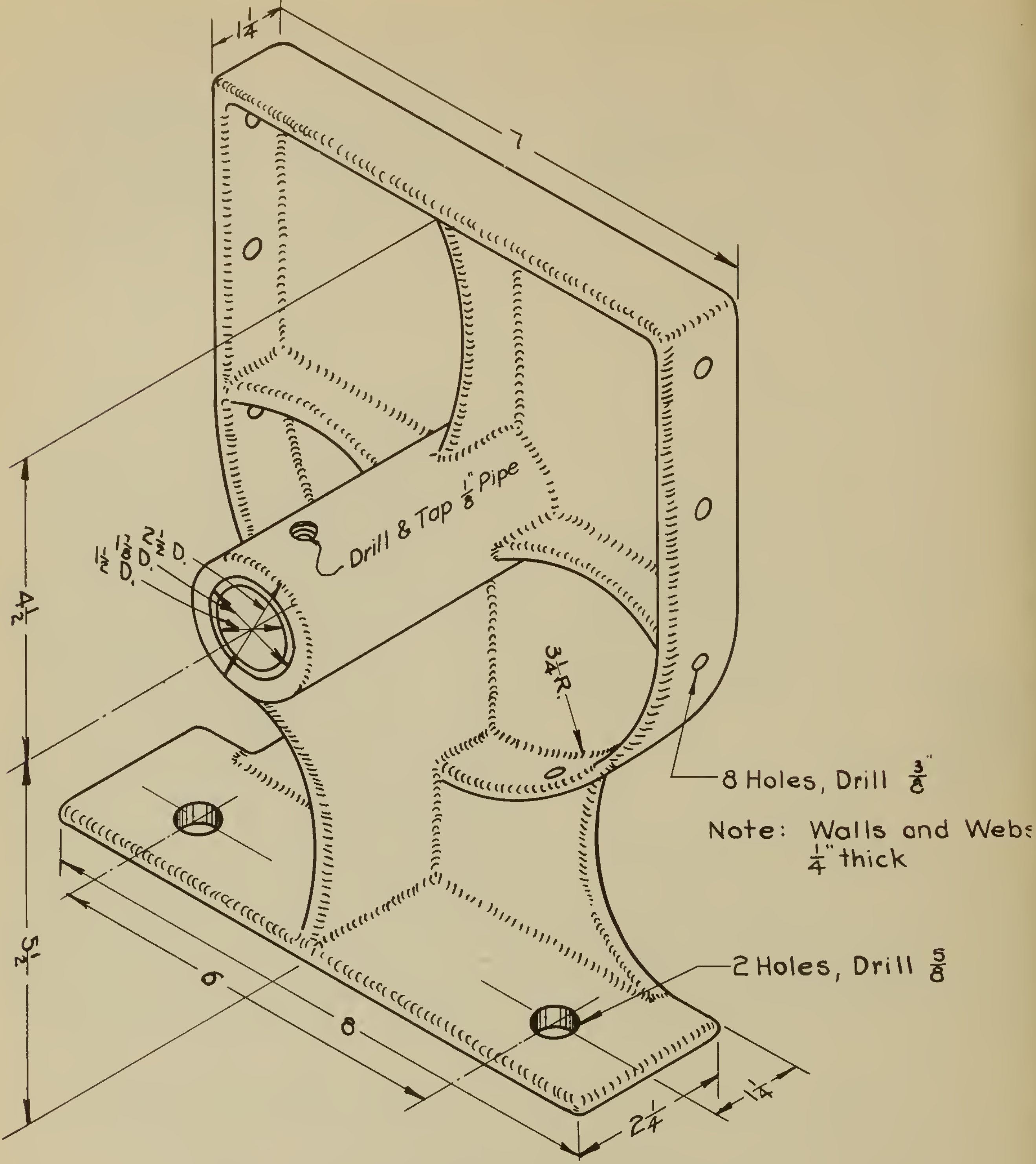


Figure 11-XV. End Bearing for Conveyor

Since the strict theories of pictorial drawing, as previously mentioned, are not followed in practice, a combination of angles and scale ratios should be chosen which will give the best results. Such a combination is often called a "dimetric drawing." Some scale ratios and angles often used are shown in positions III and IV, Figure 12-XV.

The object of reducing a scale along a certain axis is to minimize distortion in that direction. Also, the smaller the angle that a receding axis makes with the horizontal, the less distortion there will be in the corresponding vertical face. Such a reduction, however, will increase the distortion in the horizontal face. A careful study should be made of Figure 12-XV and the distortions mentioned carefully noticed.

9-XV. Trimetric. Any position of the cube, Figure 2-XV, position III, which will show all three axes foreshortened a different amount would be known as a trimetric (three measurements), sometimes called "trimetric projection."

The trimetric system is not often used in practice, although it has certain advantages in reducing distortion. See Article 8-XV. When a combination of three different scales is used, and when the two angles which the receding axes make with the horizontal are different, the representation would be called a "trimetric drawing."

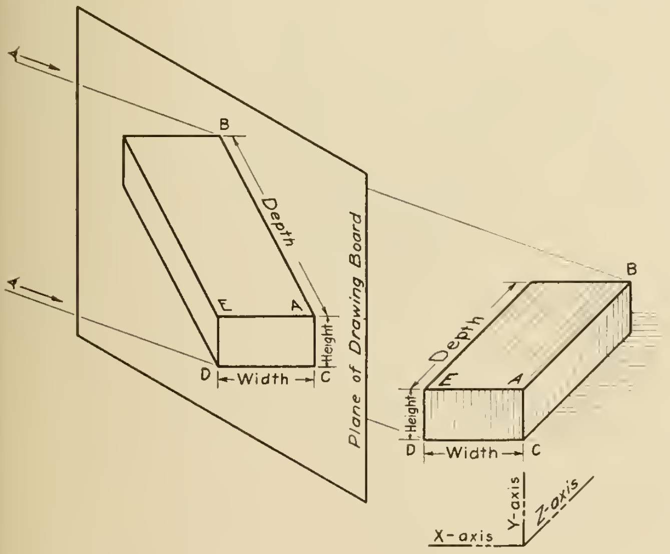


Figure 13-XV. Oblique Representation

### Oblique Drawing

10-XV. Theory of Oblique Drawing. The reader should refer to the theory of oblique drawing as outlined in Chapter V. The object is in simple position, the observer at infinity, and standing in oblique position, Figure 13-XV. Since the object is in simple position, a vertical plane can be placed in a face of the cube, ADC, Figure 14-XV. The plane might as well have been placed away from the cube but parallel to face ADC. The visual rays pierce the plane M-M at an oblique angle. Axis AB is perpendicular to M-M. Axis AD and AC are obviously in true length. Line AB in the drawing will vary from true length to zero, depending upon the angle of obliquity of the visual ray. At 90 degrees, which would be an orthographic, AB would disappear. If the angle of obliquity were 45 degrees, AB would be seen in true length, all lines parallel to the three pictorial axes would be in actual representation, and the result would be a true drawing. Such a presentation is called a "cavalier drawing." The principle is as follows: If a 45-degree cone were placed with the vertex at B, II, Figure 14-XV, and base in M-M, the visual ray as indicated would be an element of the cone, and angle BB'A would equal 45 degrees. The radius of the base AB', the cavalier drawing of AB, would be equal to the altitude of the cone, AB. Therefore AB' = AB, and the drawing of line AB is the true length of the line. The angle of obliquity is the angle of the cone. The cavalier drawing with its pictorial axes indicated is shown in position III. The visual rays might have been parallel to any of the elements of the cone--except the profile or horizontal elements. The elements which make an angle of $45^{\circ}$ with a horizontal line are used as the observer's line of sight. When the dimensions parallel to the receding axis in a cavalier drawing are reduced one-half, the result is a "cabinet drawing", Figure 15-XV on the following page. Oblique representations, other than cavalier and cabinet, are called "oblique drawings." A pleasing result is to have the angle of obliquity 15 or 30 degrees and use a scale ratio of 1:1:1. If necessary, the dimensions parallel to the receding axis could be reduced, say to 3/4 or 1/2. The result would be an imitation of the cabinet and very effective at times.

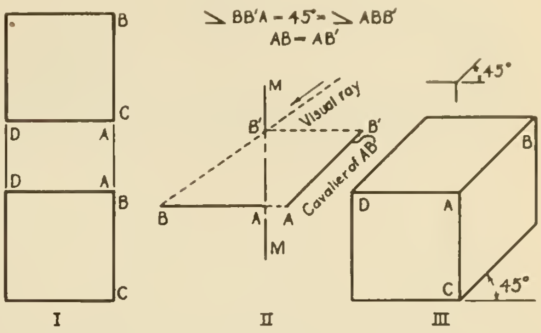


Figure 14-XV. Theory of Oblique Drawing

11-XV. Nonoblique Lines. A line that

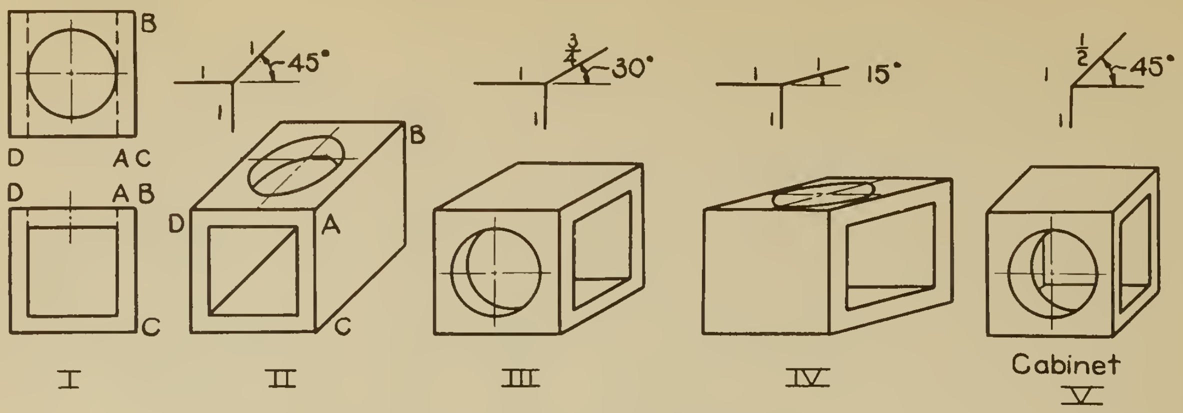


Figure 15-XV. Oblique Drawings Compared

is not parallel to an oblique axis is a nonoblique line. The nonoblique lines are located, as were the nonisometric lines of Articles 4-XV and 5-XV. It is obvious that a circle in the front face of an oblique drawing will appear as a circle. If in either of the other two faces, the results will be ellipses. The oblique circle (ellipse) should be drawn by the method of Figure 16-XV, which is the same method illustrated in Figure 8-XV and described in Article 5-XV. The two methods do not appear to be the same, due to a difference in the values of the angles between the receding axes and a horizontal plane.

12-XV. Oblique Axes. Some of the more common positions of the oblique axes are shown in Figure 17-XV. As a rule, an object should be drawn in its natural position. The axes in positions III and V are in a reversed position.

13-XV. Rules for Placing Oblique Axes. The front face of an oblique drawing is

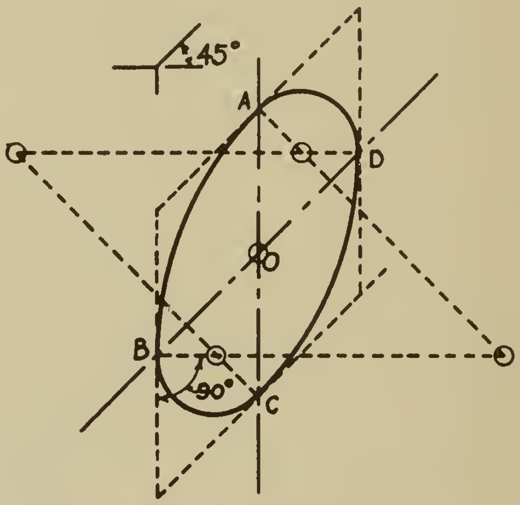


Figure 16-XV. Oblique Circle Construction

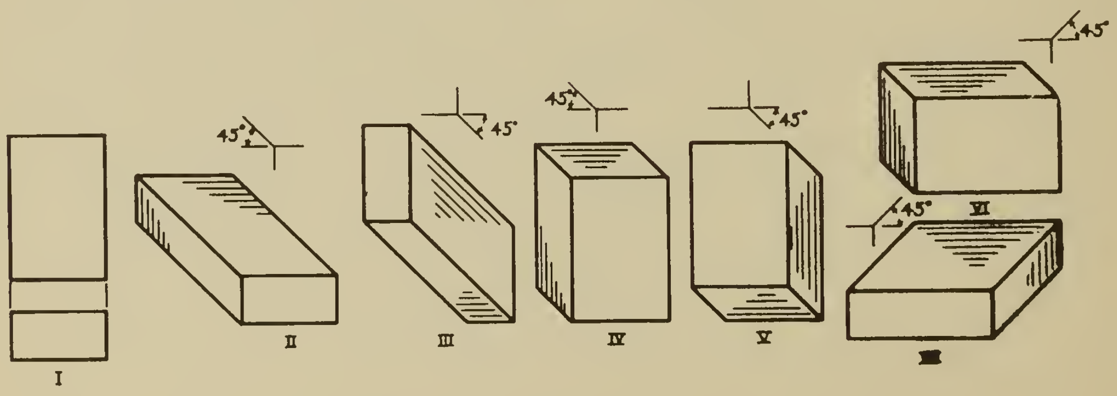


Figure 17-XV. Position of Oblique Axes

evidently a true representation of the object, an advantage over axonometric representation of objects containing circles or irregular outlines. In placing an object in oblique, the following rules should be observed: (1) Place the object so the circles and irregular curves will fall in the front face of the drawing, Figures 15-XV and 18-XV. (2) Place the longest dimension of the object in the front face of the drawing, Figures 15-XV and 17-XV. (3) If these two rules conflict, the first one should have precedence. If the receding lines are long, compared to other lines of the drawing, the lack of convergence produces distortion. The distortion can be very materially lessened by using a reduced scale on the receding lines. Circles placed in either of the receding faces, especially the horizontal, show considerable distortion, but if placed in the vertical receding face and the angle of the receding axis reduced, the distortion is very materially lessened. If possible, curved lines or any sharp detailing should be kept out of the receding faces, especially the horizontal. In this case an axonometric might be a better form of representation.

14-XV. Axonometric and Oblique Drawings Compared. Figure 18-XV, gives a comparison between axonometric and oblique drawings. The placing of axes, angles of the receding axes, scale ratios of foreshortening, and accompanying distortions spoken of in the previous articles of this chapter can be compared in Figure 18-XV. Before a drawing is begun, the draftsman should study the object to be drawn and the different methods of representation so that he may intelligently choose the method which will produce the most pleasing results. The object of Figure 19-XV is ideally suited for the oblique presentation.

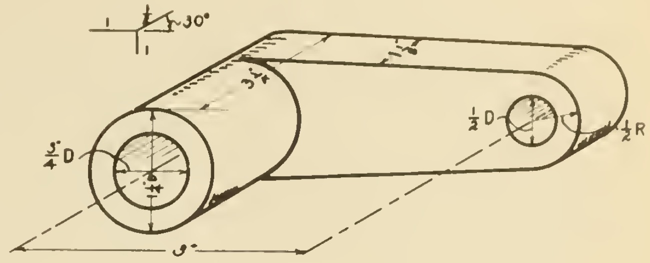


Figure 19-XV. A Study in Oblique

15-XV. Shade and Shadow Representation. Only two rectangular dimensions can be drawn in a plane surface. Since drawings are made in planes, the third dimension depth must be represented to the eye by some artificial means. When this is not done, there is too much flatness and it is too difficult to visualize the depth of an object which is perpendicular to the surface of the paper. Shades and shadows are used by artists and architects to bring the object into relief and thereby aid the eye in visualizing depth.

The engineer is not so much concerned with the above representations in obtaining the relief effect on his drawings. He omits shadows entirely and uses ruled lines to represent shading, called line shading. He seeks to obtain a contrast between surfaces, emphasizing some, suppressing others. He

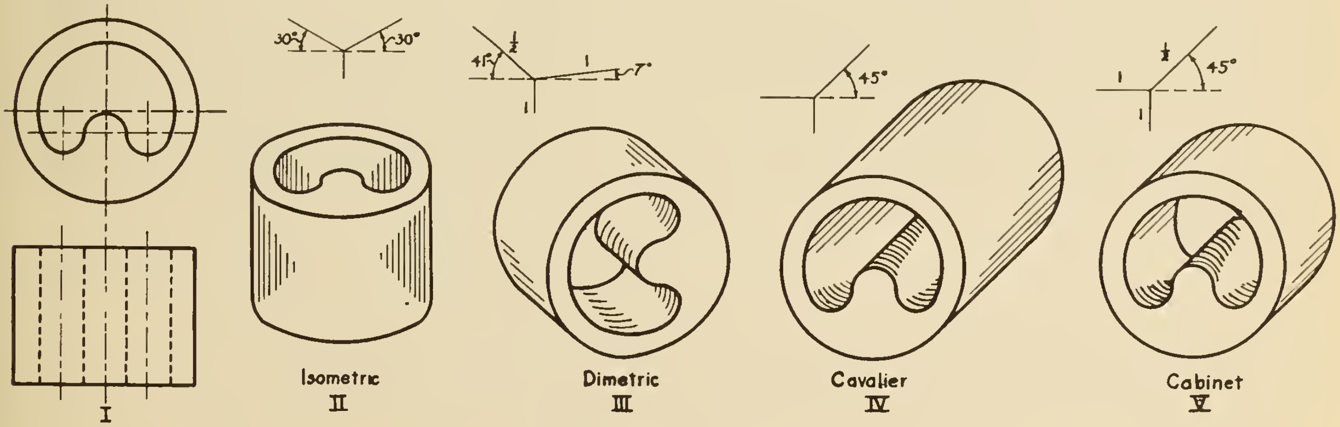


Figure 18-XV. Axonometric and Oblique Drawings Compared

violates the strict principles of shading for simplicity. As a general rule (1) the surfaces perpendicular or nearly perpendicular to the line of sight are not shaded; (2) surfaces or parts of surfaces farthest from the observer receive the heaviest shading; (3) curving surfaces may be shaded with either straight lines or curved lines as illustrated; (4) a small amount of shading is more effective than a lot of shading--a contrast in surfaces is sought; (5) drawings which do not contain hidden outlines (dotted lines) should be treated with line shading. This applies to sectional views, assembly drawings, and pictorial drawings.

Figure 17-III (page 32) illustrates the method of line-shading a sphere, and in many of the following illustrations methods of shading cylinders, cones, prisms, and other elementary structures can be found and should be studied. The principles can then be applied when shading the more complicated drawings. Numerous illustrations can be found in this chapter.

16-XV. Pictorial Dimensioning. The general rules for dimensioning working drawings will apply here. (Some of the special rules will not.) In addition to the general rules, the following ones should be added for pictorial drawings:

1. Dimensions should be read from the lower center of the drawing.

2. A witness line or a dimension line should be drawn parallel to one of the pictorial axes.

3. A vertical style of lettering should be used.

4. All lettering should be placed so that it lies in the plane of the witness lines and dimension lines. To check this rule: A line sketched through the center of the letter or numeral should be parallel to the witness lines of that dimension. This will give the effect of vertical lettering, rule 3.

5. When convenient, dimensions may be placed on the face of the drawing.

The above rules should be checked in Figures 13-VI, 10-VII, 11-VII, 2-XII, 11-IV, and 11-XV.

## EXERCISES

17-XV. The following problems furnish excellent reading exercises in translating from orthographic to pictorial and for making pictorial drawings. The problem spaces and scales will be given for each group.

Group 1-XV. Axonometric Drawings. Dimension all drawings

1-4. Make isometric drawings. Figures 15-VIII (page 80), 22-XV. Problem space 5 1/8 x 8, Figures 20-XV, 21-XV. Problem space 8 x 8. Scale for all drawings 3/4" = 1".

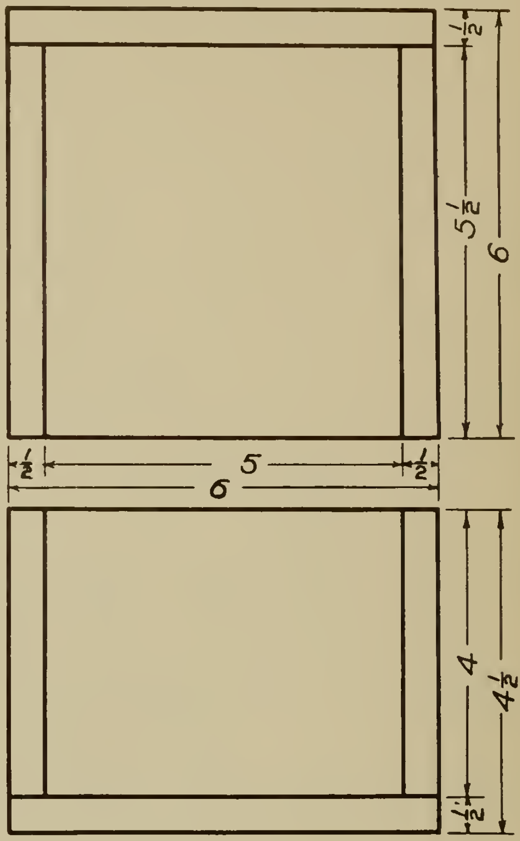


Figure 20-XV. Bracket

5-9. Make isometric sections (half sections or full sections as directed). Problem space 5 1/2 x 8. Scale 3/4" = 1". Figures 5-X (page 91), and 6-X (page 92). Exhaust-intake valve housing, Figure 28-XV; gas engine governor timing gear, Figure 29-XV; gas engine piston, Figure 19-XIV.

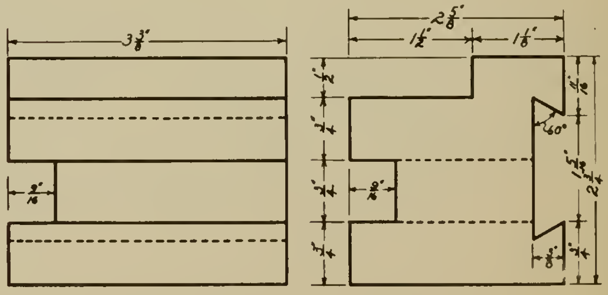


Figure 21-XV. Turning Tool Holder

10-12. Make dimetric drawings. Problem space 8 x 8. Scale 3/4" = 1". Figures 10-VIII (page 79), 12-VII (page 70), and 14-VIII (page 80).

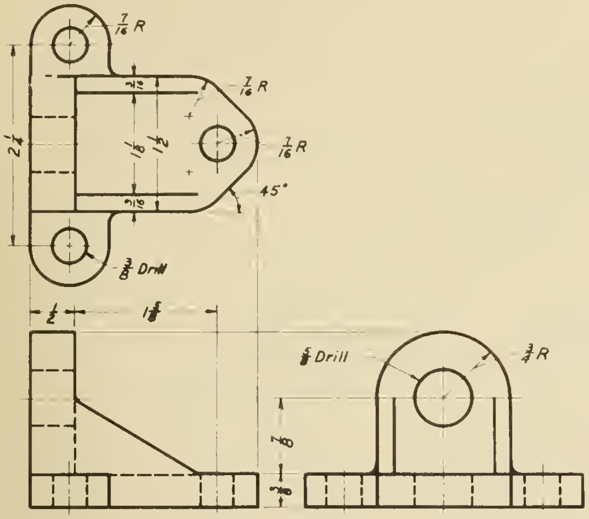


Figure 22-XV. Sand Box Bracket

## Group 2-XV. Oblique Drawings

1-3. Make oblique drawings as indicated. Problem space 5 1/2 x 8, scale 3/4" = 1". Figure 4-X (page 91) (cavalier). Figures 12-VII (page 70), 23-XV. (Angle of obliquity 30 degrees.)

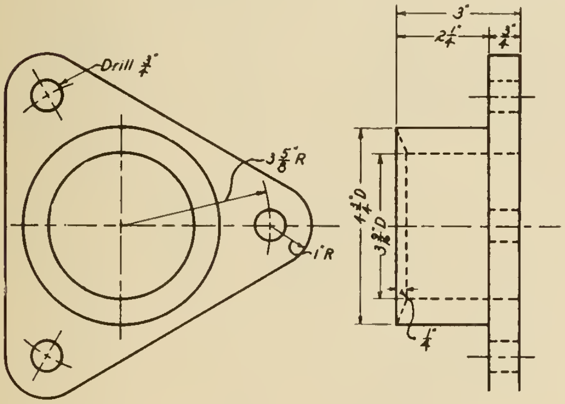


Figure 23-XV. Stuffing Box Gland

4-5. Make cabinet drawings. Problem space 5 1/2 x 8, scale 3/4" = 1". Figures 24-XV, 25-XV.

## Group 3-XV. Miscellaneous Pictorials

1-20. Make pictorial drawings of the following figures. Use the type of pictorial which will best represent the objects. The student should determine the problem space required and select the scale for these exercises. Figures 11-VIII, 13-VIII, 17-VIII, 7-VII, 14-VII, 15-VII, 26-XV, 17-XIV, 18-XIV, 20-XIV; and an assigned part of 27-XV, 28-XV, and 29-XV; float valve, Figure 27-XV, see bill of material. Figures 3-XVI, 4-XIV, 5-XIV, 6-XIV, the pawl of Figures 4-XIV, 8-XIV, and 9-XIV.

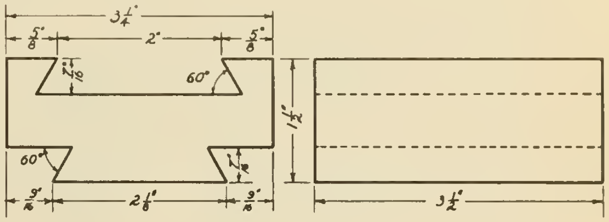


Figure 24-XV. Dovetail Cross Slide

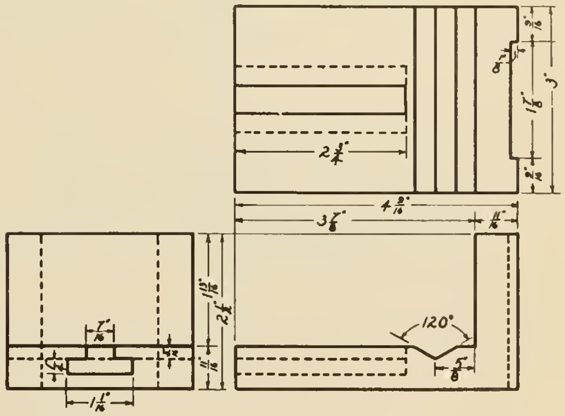


Figure 25-XV. Jig Base

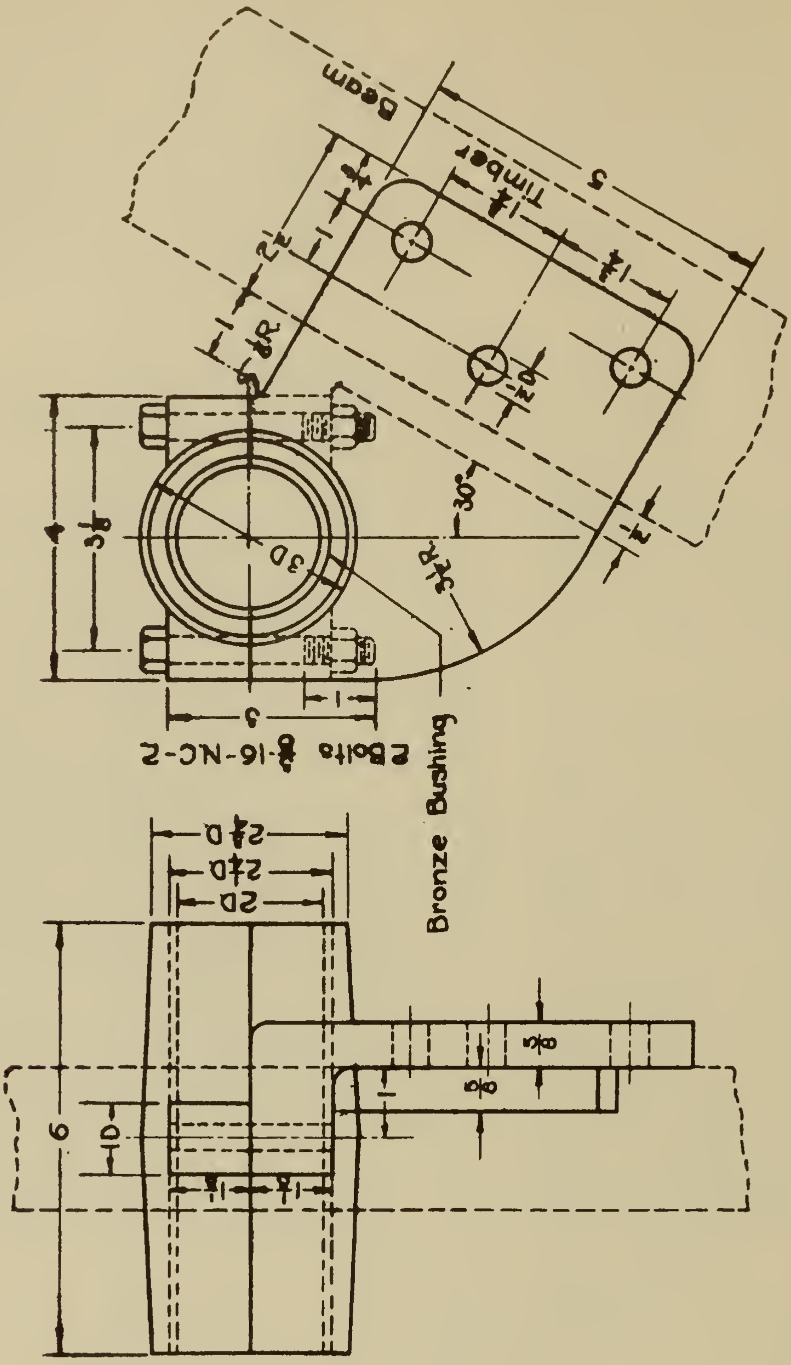
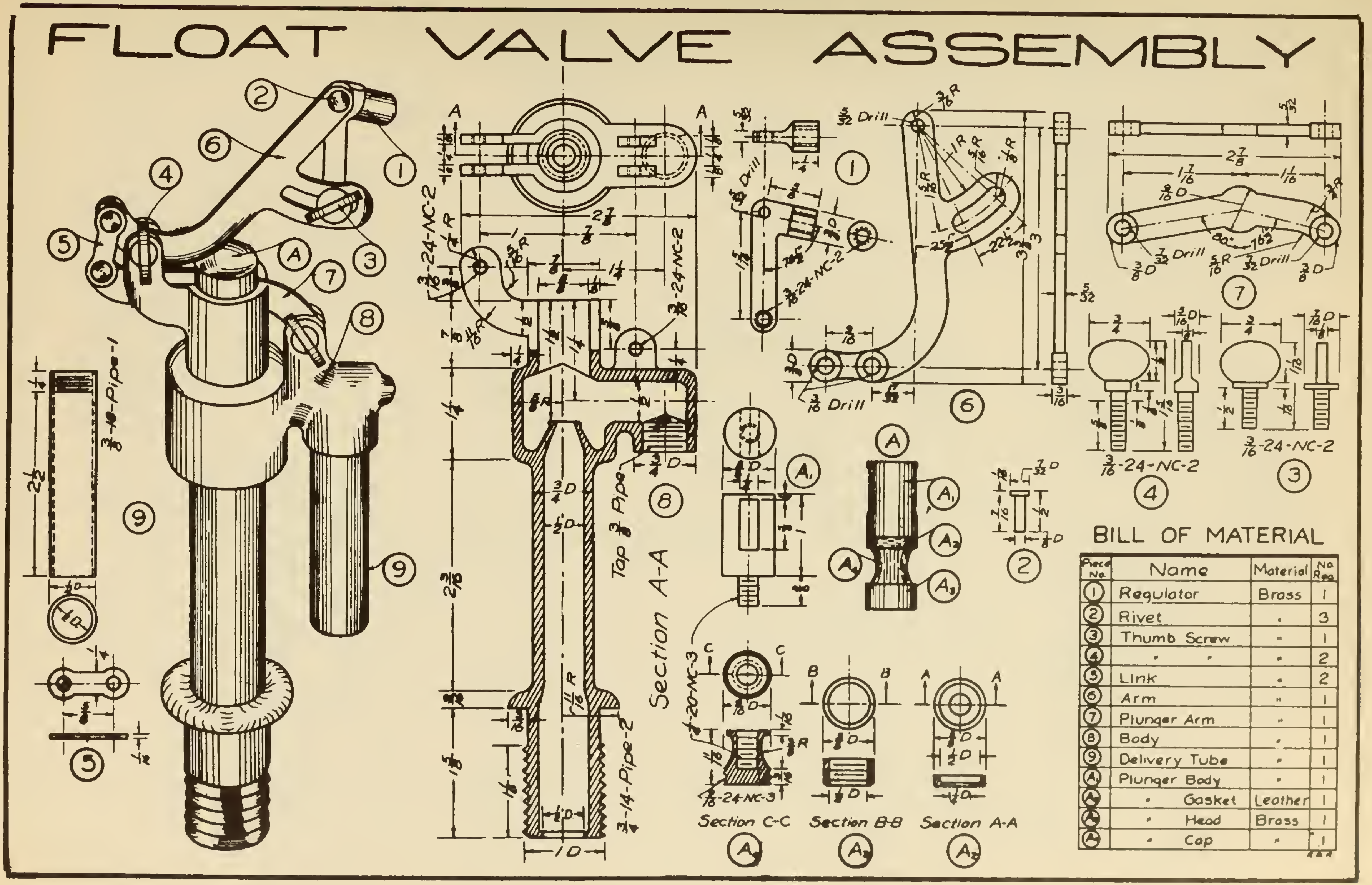


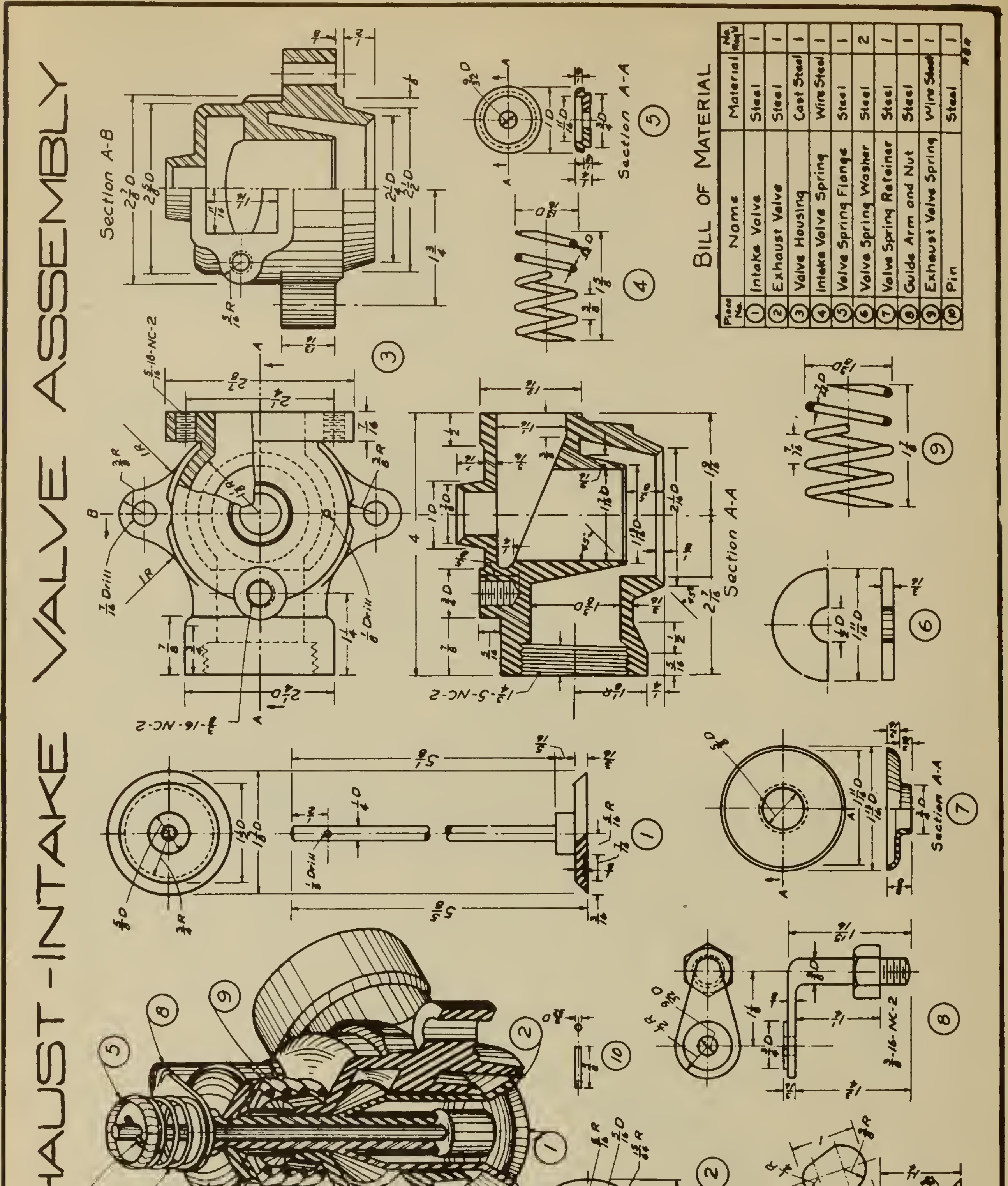
Figure 26-XV. Elevator Bearing



BILL OF MATERIAL

| Piece No | Name | Material | No Req |
|---|---|---|---|
| ① | Regulator | Brass | 1 |
| ② | Rivet | " | 3 |
| ③ | Thumb Screw | " | 1 |
| ④ | " " | " | 2 |
| ⑤ | Link | " | 2 |
| ⑥ | Arm | " | 1 |
| ⑦ | Plunger Arm | " | 1 |
| ⑧ | Body | " | 1 |
| ⑨ | Delivery Tube | " | 1 |
| Ⓐ$_1$ | Plunger Body | " | 1 |
| Ⓐ$_2$ | " Gasket | Leather | 1 |
| Ⓐ$_3$ | " Head | Brass | 1 |
| Ⓐ$_4$ | " Cap | " | 1 |

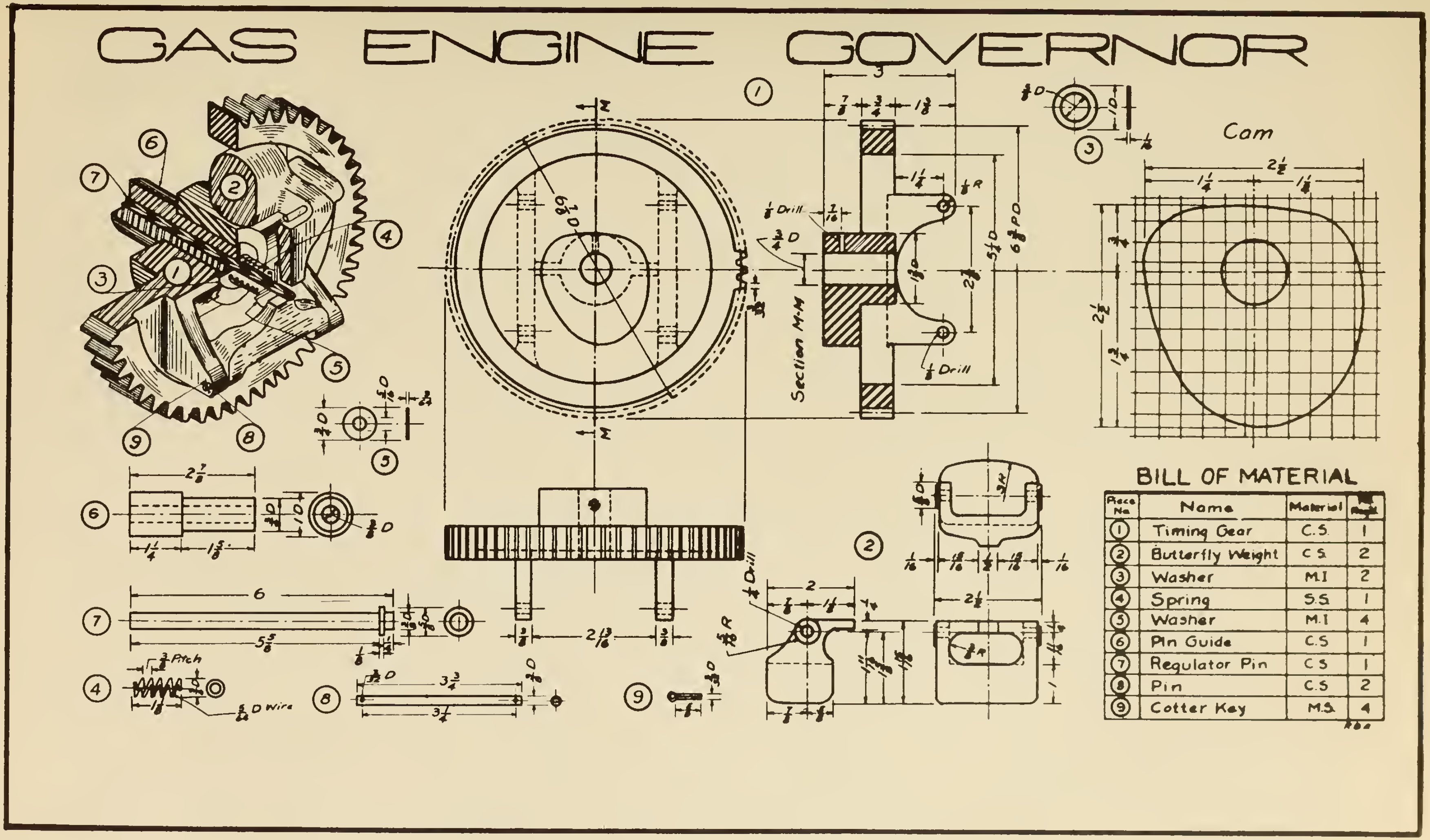
Figure 27-XV. Float Valve Assembly



BILL OF MATERIAL

| Piece No. | Name | Material | No. Req'd |
|---|---|---|---|
| ① | Intake Valve | Steel | 1 |
| ② | Exhaust Valve | Steel | 1 |
| ③ | Valve Housing | Cast Steel | 1 |
| ④ | Intake Valve Spring | Wire Steel | 1 |
| ⑤ | Valve Spring Flange | Steel | 1 |
| ⑥ | Valve Spring Washer | Steel | 2 |
| ⑦ | Valve Spring Retainer | Steel | 1 |
| ⑧ | Guide Arm and Nut | Steel | 1 |
| ⑨ | Exhaust Valve Spring | Wire Steel | 1 |
| ⑩ | Pin | Steel | 1 |

Figure 28-XV. Gas Engine Valve Assembly



BILL OF MATERIAL

| Piece No. | Name | Material | [illegible] |
|---|---|---|---|
| ① | Timing Gear | C.S. | 1 |
| ② | Butterfly Weight | C.S. | 2 |
| ③ | Washer | M.I | 2 |
| ④ | Spring | S.S. | 1 |
| ⑤ | Washer | M.I | 4 |
| ⑥ | Pin Guide | C.S | 1 |
| ⑦ | Regulator Pin | C.S | 1 |
| ⑧ | Pin | C.S | 2 |
| ⑨ | Cotter Key | M.S. | 4 |

Figure 29-XV. Gas Engine Governor Assembly

## CHAPTER XVI

## SKETCHING

1-XVI. Sketching is the engineer's method of expression. It should be an adequate and complete representation of an object, a rapid expression in the graphic language. It represents a mastery of the language and is the method of presentation used by the engineer, designer, draftsman, inventor, and other technical men to put forth their ideas when thinking along mechanical lines.

As far as the engineer is concerned, it might be said that the previous chapters of this work are but a foundation for the one on sketching. It is not meant that a sketch is something that is drawn roughly or inaccurately. It should be an engineering drawing, in orthographic or pictorial, made free hand.

2-XVI. Application. Preliminary designs are first worked up in sketches, afterward elaborated on, and probably working drawings are made from them later. It might become necessary to go a considerable distance from the drawing room to get certain information on repairs, redesign, or operation and maintenance records. Sketches or data thus obtained might be next to worthless if incomplete. Sketches should not be cluttered with unnecessary details. But of the two, too much information (details) is by far better than not enough. Mistakes, such as omissions of minor details, dotted lines that should appear as full lines, wrong position of relatively minor parts, and similar errors, that would be discovered quickly in making a scaled drawing, often occur in a sketch. However, constant care should be exercised to prevent too frequent occurrence of such mistakes.

Foremen or salesmen often find it necessary to send information to the main office by means of sketches. The engineer is often called on in a committee or board meeting to present his ideas or explanations by making sketches.

3-XVI. Classification of Sketches. Sketches may be divided into two general classifications:

A. (1) orthographic (multiview) sketches and (2) pictorial sketches
B. (1) design sketches and (2) reproduction sketches.

Emphasis is laid on the second classification, and either orthographic or pictorial representation will be used in executing the sketches of classification B.

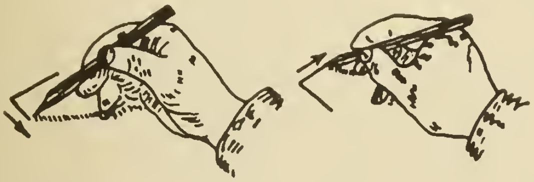
Design sketches may be classified as: (a) Idea sketches are used in developing and perfecting the design of a machine or structure, arrangement of the various parts, or sketches used in obtaining the proper proportions or balance when designing. (b) Sketches of design principles are set forth and emphasize the principles involved in the design. These are particularly useful in developing designs that are to be patented later. (c) Detail sketches are to set forth the various details of the design, to furnish dimensions and certain specifications. (d) Assembly sketches are used to show the machine, plant, or structure in assembly with over-all dimensions and the dimensions locating the principal units or parts (center line to center line, etc.). (e) Kinematic sketches show the path of moving parts and furnish velocity diagrams with accompanying calculations for motion and strength. (f) Diagram sketches are convenient for laying out stress diagrams, vector diagrams (sometimes used in (e) above), and similar uses, for purposes of computations or analysis. (g) Location sketches are used to locate piping or wiring layouts, shafts and pulleys, floor plans for locating machinery and putting in machine bases, floor plans of a room or building, or a block plan to locate buildings or other improvements. (h) Computation sketches are very useful when making computations and for illustration purposes.

Reproduction sketches are for the purpose of reproducing objects that are in existence, copying photographs or illustrations, or reproducing designs that have previously been made. This is a very wide field for sketching. They include (a) assembly, (b) detail, (c) diagram, (d) location and (e) computation sketches as described above.

4-XVI. Materials. As previously stated, sketching is done free hand without the aid of instruments or tools. The only necessary materials are a soft pencil (F or H) with a long conical point, a soft eraser with ends whittled to a sharp chisel point, and paper. The paper may be bound in notebook form, in pads, in sheets inserted in a clipboard, or sheets tacked on an easel. The paper might be plain or ruled with coordinate lines (rectangular coordinates or isometric coordinates).

When taking dimensions of an object to be placed on a sketch, a two-foot scale and inside and outside callipers are necessities. Other tools might also be required, such as micrometer callipers, try square, fillet gage, thickness gage, screw pitch gage, wire gage, surface gage, depth gage, and plumb bob.

5-XVI. Technique. The pencil should be held with a light touch, not too close to the point, and pencil lines should be sketched in lightly with a series of overlapping strokes, holding the hand in one of the two positions of Figure 1-XVI. Long lines are with arm motions. Short lines are drawn with finger motions. The draftsman should be in a position, while sketching, to prevent muscular cramps or binding from clothes. When drawing a horizontal line from right to left, muscular tension and the binding of the clothes tend to pull the hand down. The effect will be a curved line dropping down and to the left. Horizontal lines should be drawn from left to right, Figure 1-XVI. Vertical lines should be drawn from top to bottom unless the line is relatively long, in which case the pulling effect mentioned above will be felt. The draftsman should shift his position counterclockwise through 90 degrees (clockwise if left handed) and sketch from left to right (bottom to top) or shift the paper, which would produce the same result. When sketching a straight line, one should keep the eye in the direction of the line to be sketched, leading the hand by several inches, rather than on the point of the pencil. A long line should not be drawn with one stroke. It might help to sketch a preliminary line first, very lightly, and then go back over it, brighten it up, and take out kinks without making erasures. Long lines might be drawn by using the small finger as a guide along a straight edge--say the edge of the paper, board, or an instrument--moving parallel to the line to be drawn. When drawing inclined lines, the draftsman should shift his position or turn the paper and follow the rules for sketching horizontal and vertical lines given above.



To Sketch a Vertical Line

To Sketch a Horizontal Line

Figure 1-XVI. Line Sketching

Center lines for circles should be sketched first and then a square drawn (sides equal to the diameter of the circle) Figure 2-XVI (B), or 45-degree lines sketched as at A. The circle can then be drawn, as shown, after the radius has been laid off (approximately) on the various lines. After a draftsman has had considerable practice in sketching, he should be able to draw the larger circles by using the small finger as a pivot and revolving the paper while the pencil is held stationary.

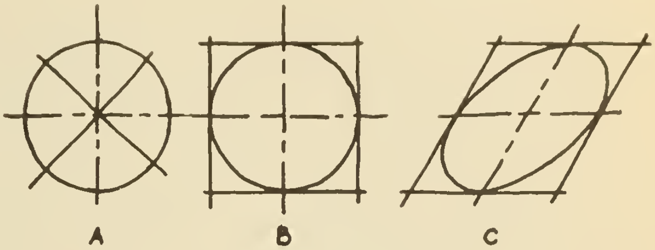


Figure 2-XVI. Circle and Ellipse Sketching

The ellipse is drawn by first sketching the pictorial axes (or conjugate diameters), then laying off the radius of the circle on the axes and completing the parallelogram, Figure 2-XVI. The ellipse is finally sketched by quadrants. If a hexagon is to be drawn, the six points can be located symmetrically on the circumference of the ellipse, bearing in mind that the upper right and lower left quadrants (as shown) are obviously shortened very materially. The points can then be connected, forming the required hexagon in pictorial. The orthographic hexagon can be drawn by dividing the circumscribed circle into six equal parts and connecting the points.

6-XVI. Orthographic Sketching. Orthographic sketching, classification (A), Article 3-XVI, is generally used for engineering sketch representation, Figure 3-XVI on the following page. Before beginning, the draftsman should study the object carefully, decide upon the number and kind of views to be drawn, and apply the various rules previously given for making an orthographic drawing. An experienced person will save time when violating some of the above rules by drawing half- or quarter-views of symmetrical objects, by omitting minor views, and supplying such information as the diameter, square,

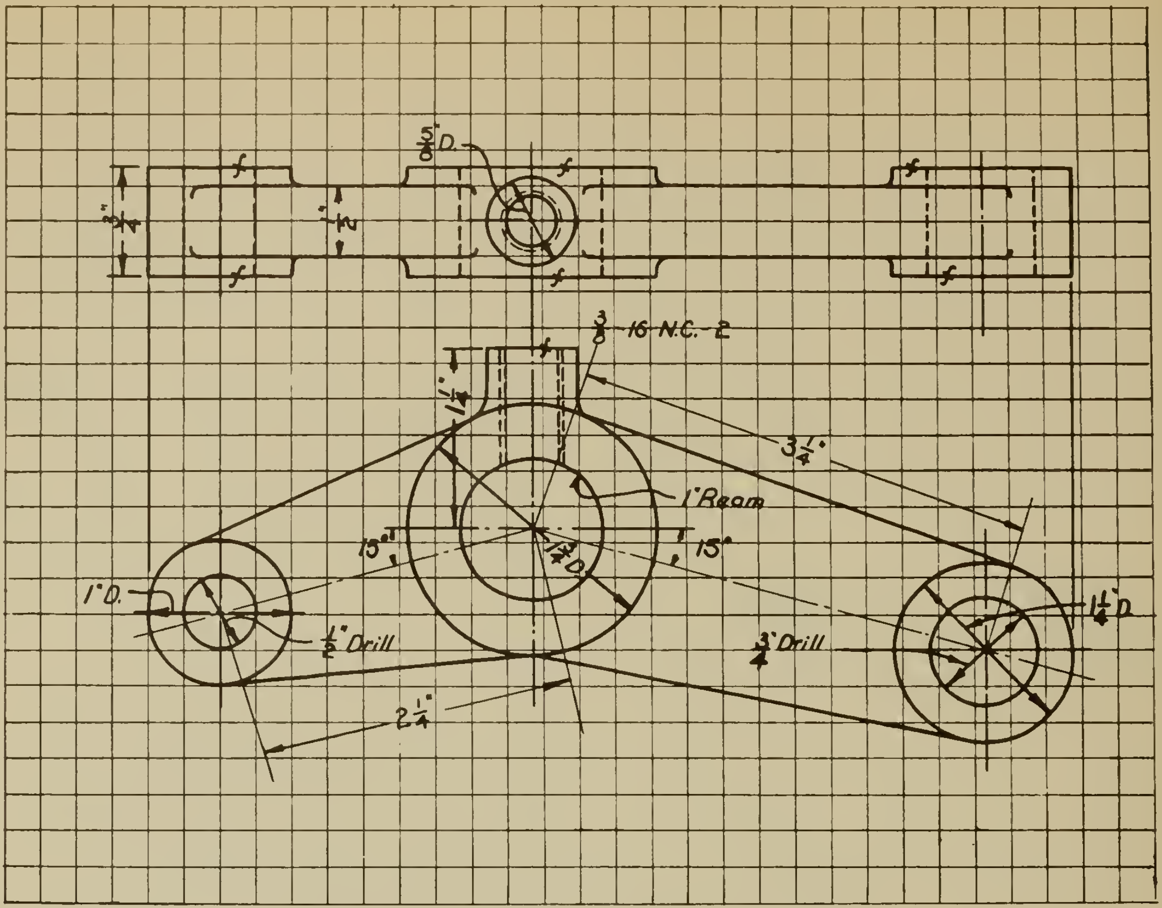


Figure 3-XVI. Rectangular Coordinate Sketching

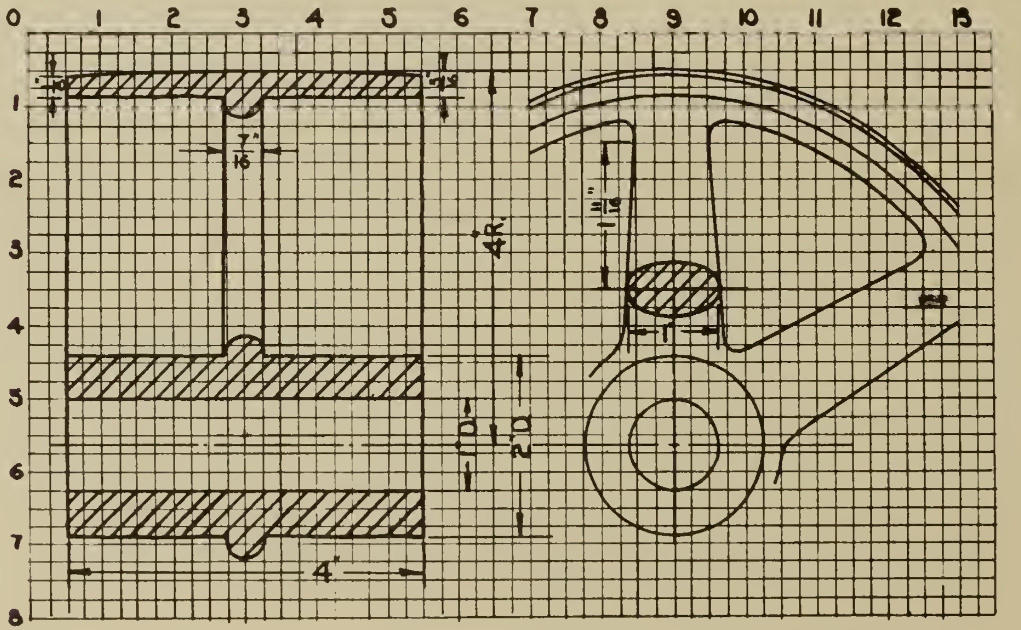


Figure 4-XVI. Partial View Sketching

thickness, etc., Figure 4-XVI. The beginner however, should not follow this procedure.

It is usually necessary to reduce the dimensions of an object when laying out a sketch. Before beginning, the draftsman should study the object carefully as to (1) dimensions, (2) positions of the various parts composing the object, and (3) relative proportions of the object. The proper proportion should be kept throughout the drawing, as well as the relative reduction of the lengths of lines (scale reduction), but it should be remembered that no dimensions are actually taken. After (4) space for the various views has been estimated, (5) center lines for the several parts drawn in, (6) the holes, bosses, shafts, bolts, and the like should be sketched, after the box construction has been made, (7) then the minor details can be added, and (8) dimensions, notes, and title placed. (9) If a line contrast is desired, the drawing can be gone over and the visible outlines brightened. These steps should be kept in mind for orthographic sketching.

Objects should be drawn resting in their natural position. Notes should be used freely, Figure 5-XVI on the following page, but the sketch should not be cluttered with unnecessary data. Rectangular coordinate paper can be used to advantage, Figure 3-XVI. A division of 8 or 16 to the inch (rather than 10) is desirable when using the architect's scale, Figure 3-XVI and Figure 4-XVI.

7-XVI. Pictorial Sketching. Pictorials are used a great deal in engineering sketching. The uses and advantages of pictorial drawings have been referred to and will in a general way apply here. Working drawings that are difficult to understand, unusual and difficult details can best be shown in pictorial. Small objects can easily and quickly be sketched in pictorial. When describing an object, explaining a drawing or detail, it is very effective to be able to augment one's description or explanation with a pictorial sketch, especially when dealing with nontechnical observers. One of the best ways to read difficult details in an orthographic is to start making a pictorial sketch. Before the sketch is finished, the difficulty is usually cleared up. The pictorial axes should first be sketched and then the rules for sketching, Article 14-XVI, followed.

The three pictorial methods of presentation are: (1) axonometric, (2) oblique, and (3) perspective. The pseudo-perspective is used in this chapter.

8-XVI. Axonometric. A variation of the isometric is usually used in axonometric sketching. That is, instead of drawing the receding axes at 30 degrees with the horizontal, angles of 15 degrees can be used to advantage in reducing distortion, as previously explained. However, there is a decided advantage in sketching on isometric coordinate paper, Figure 6-XVI. It is convenient (1) in drawing parallel lines, (2) keeping the proportions of the object, and (3) locating the positions of the various parts.

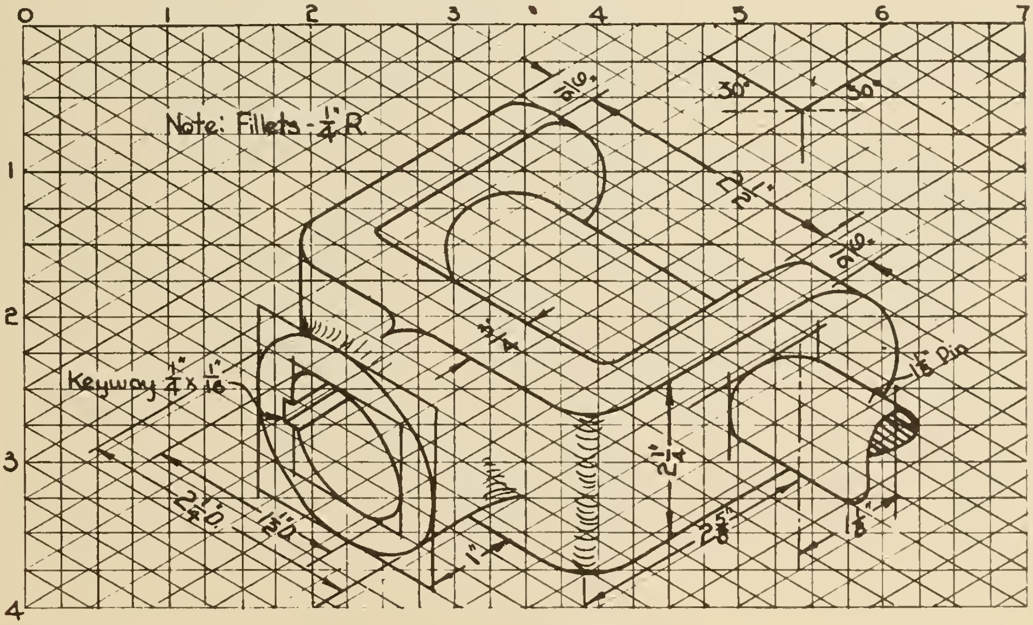


Figure 6-XVI. Isometric Coordinate Sketching

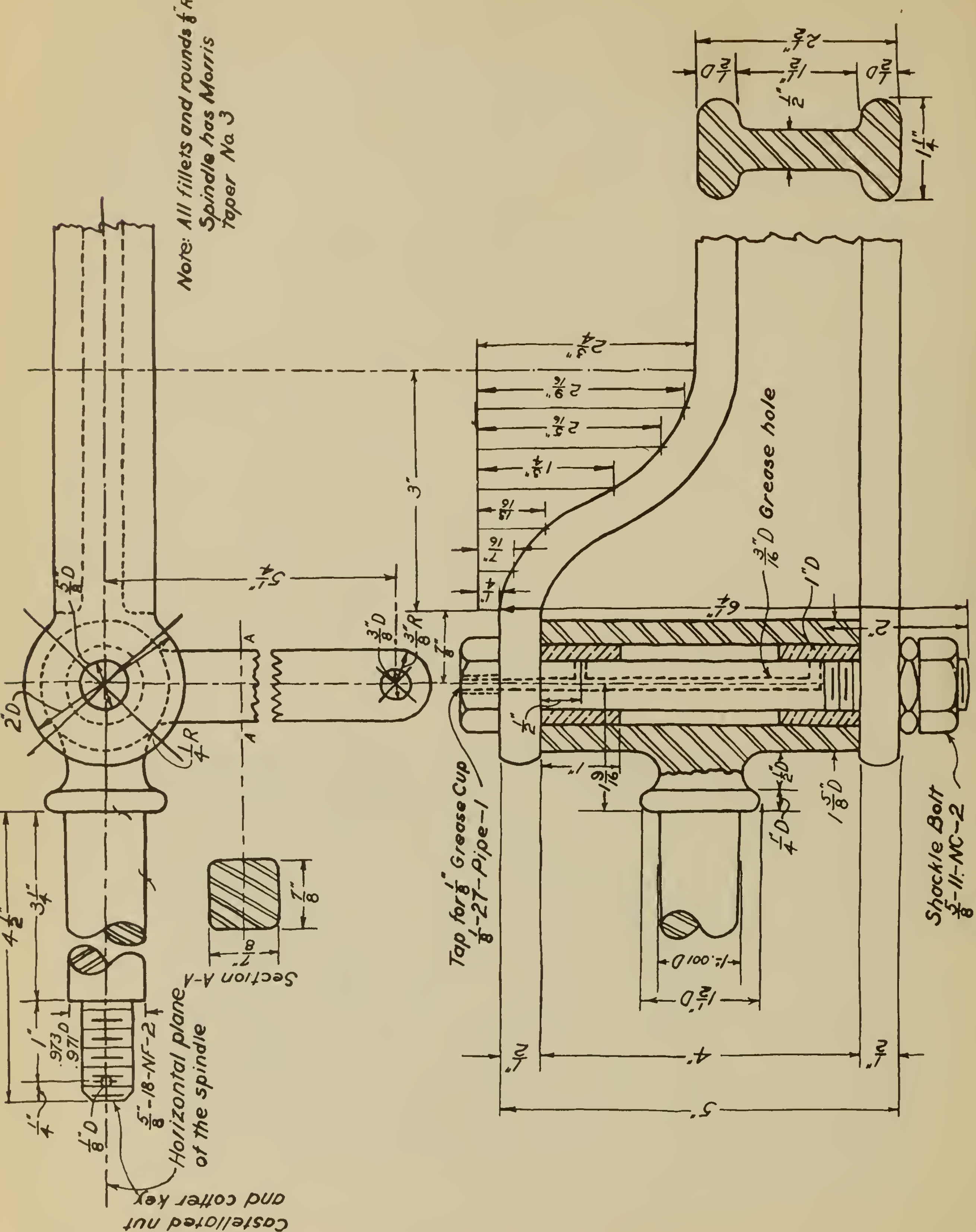


Figure 5-XVI. Assembly--Detail Sketch

When sketching on ordinary paper considerable distortion can be eliminated by having receding parallel lines slightly converging.

Pictorial coordinates axes can be ruled with the desired receding angles, placed underneath sketching paper, and used as guide lines in axonometric sketching. This will effect a considerable saving in time. The isometric receding angles with the horizontal are 30 degrees, but flatter angles can be used to advantage, say 7 1/2 or 15 degrees.

9-XVI. Oblique. Oblique representation has a decided advantage when sketching an object which has all, or practically all, of the curved and other characteristic lines in one face. Considerable distortion can be eliminated by having the receding lines converge slightly (rather than parallel), and if necessary the receding lines can be foreshortened. See Figure 13-XVI. The steps, Article 14-XVI, for laying out a sketch should be followed. Receding axes should be kept flat, 15 or 30 degrees from a horizontal plane.

Oblique coordinate axes, with the desired angle of obliquity, say 15 or 30 degrees, can be ruled and used as described in Article 8-XVI.

10-XVI. Pseudo-perspective. When the observer is stationed at a finite distance and views an object from an oblique position, the representation is called a perspective drawing, Figure 7-XVI. The observer is standing at A, a point directly in front of BC, and on a level with the horizon. The object is below the observer, and the blade and beam make equal angles with the horizon. The horizon is an imaginary line which represents the meeting of the sky and land and of course is at infinity. Receding lines vanish to points, $V_R$ and $V_L$, on a level with the horizon. The observer's eye or station point, S, is always on a level with the horizon. Since the blade and beam make equal angles with the horizon, distances $SV_R$ and $SV_L$ are equal.

Equal distances on the front vertical edge of an object are represented by equal lengths in perspective. Line BC, Figure 7-XVI, is divided into three equal parts, and they appear equal. However, the vertical distance DE is equal in length to BC but appears much shorter, due to convergence. The horizontal marks on the blade which represent one-inch divisions appear closer and closer together as the end of the blade is approached, due also to converging lines.

Figure 8-XVI, on the following page, is a sketch of a one-inch cube. The vertical face makes an angle of 45 degrees with the horizon and with the direction in which the observer is looking. It is sometimes called the 45-degree perspective. In the 45-degree perspective of Figure 8-XVI, the distance from the station point and from the vanishing points to a point A is 14 inches. Point A is directly above BC and directly in front of S (on a level with the horizon).

Since the side faces of the cube are equally inclined to the direction in which the observer is looking, (1) angle DBF = angle D'BF', (2) angle ECG = angle E'CG' and are the angles of inclination. The perspective of corner H is directly above corner B. Due to convergence, (3) angle ECG is more than angle DBF and (4) angle E'CG' is more than angle D'BF'. (5) Lines DE and D'E' are equal and less than line BC. Also (6) HD and HD' are equal and less than BD and BD'. (7) Distance HK is shorter than KB, and (8) BD and BD' are shorter than BC. The above 8 significant points should be kept in mind when sketching. If the vanishing points fall off the problem paper, the approximate angles

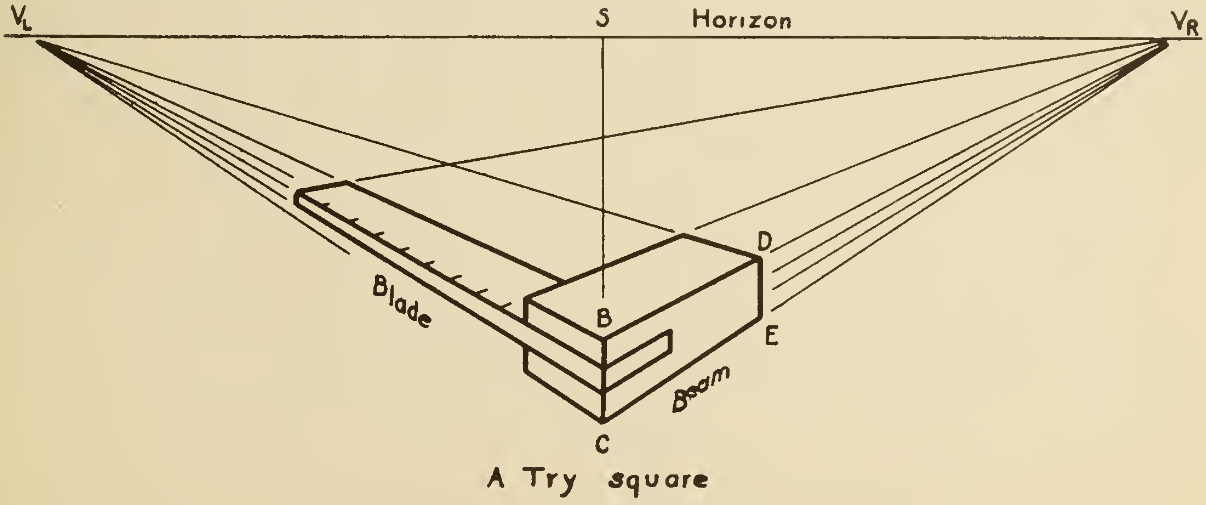


Figure 7-XVI. Pseudo-Perspective

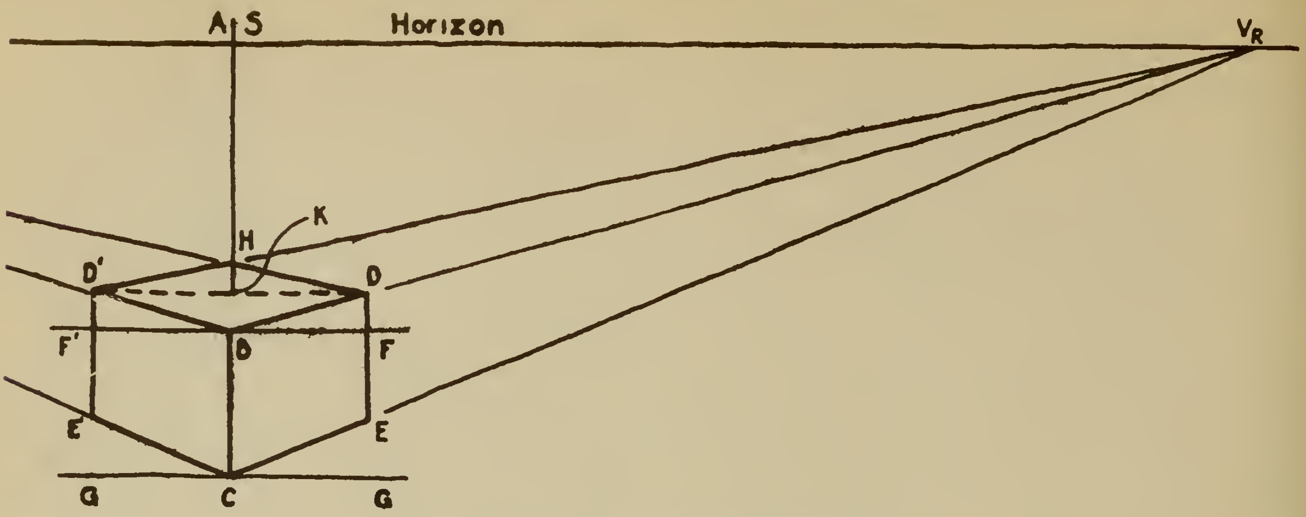


Figure 8-XVI. Perspective of a Cube

D'BF', etc., can be sketched and the drawing completed without actually locating the points. It might be well to locate at least one point, $V_R$ in the sketch, if possible. The beginner should study Figure 8-XVI in order to get an idea of distances and foreshortening of a one-inch cube so that proportional distances and foreshortening can be used when sketching other objects.

In order to obtain the width of a vertical face of a cube, draw DE so that figure BDEC appears to be a square. Figure 9-XVI, shows the process of trial and error of locating DE. It might be necessary to sketch a number of lines, as FG and HI, before the proper one, DE, is located. All trial lines should be erased before another "square" is drawn.

Vertical distances of an object should be measured in perspective on the front vertical edge and then this distance carried, to the right or left, to the proper position in the drawing. That is, line BC, Figure 8-XVI, is seen in true length, but when carried to the edge of the cube to the right at DE, or D'E' to the left, the line is considerably foreshortened.

The size of the figure representing a horizontal square, the length of the minor axis of an ellipse representing a horizontal circle, and the angles of inclination, a, increase with the distance of the object below the level of the eye, Figure 10-XVI. One-inch cubes and one-inch cylinders with one-inch altitudes are here represented. The numerals indicate in inches the distances the front points, P, in the horizontal faces are below the horizon, with corresponding angles of inclination, a, for the various distances.

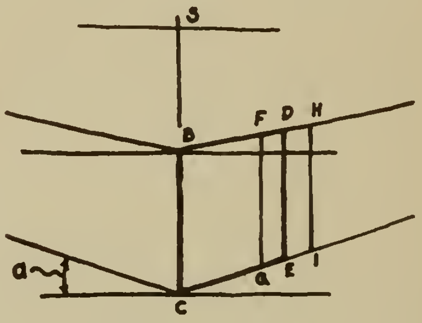


Figure 9-XVI. To Draw a Square

Such a scale will give the student an idea of how distortion in a horizontal figure will vary with the angle of inclination. The smaller the angle, however, the less distortion there will be in the two vertical faces of the cube.

When sketching, the draftsman assumes the angle of inclination, a, Figure 10-XVI on the following page, or assumes the positions of the vanishing point, Figure 7-XVI, and in this case assumes a 45-degree perspective. When such assumptions are made, instead of determining these various measurements accurately, the result is a pseudo-perspective (false-perspective).

11-XVI. Steps in Sketching. Figure 11-XVI, (1) Draw an imaginary box, for the purpose of construction only, just large enough to enclose the object. (2) Sketch a one-inch cube-in the upper front corner, edge AB. (3) Draw the vertical faces of the cube to the right and to the left, as illustrated in Figure 9-XVI. (4) Lay off vertical distances along the front vertical edge, AC, and carry them to the right or left, as the case might

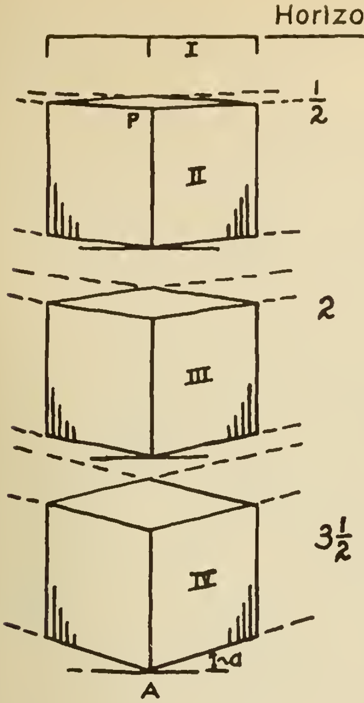


Figure 10-XVI. Scale of Angles

be, with converging lines. Thus the cube serves as the vertical and horizontal unit of measure, and the method just described is known as the unit cube method of estimating distances. (5) Sketch the center lines, boxes, or other construction lines for the various parts of the object. Draw the parts. (6) Go over the drawing and brighten the outlines by making them heavier. Erase the construction lines. (7) Place the witness lines and dimension lines on the drawing. Take measurements for the dimensions from the object as described in Article 13-XVI and place on the drawing. Add a little line shading. (8) Put on the necessary notes and the title and sign the sketch.

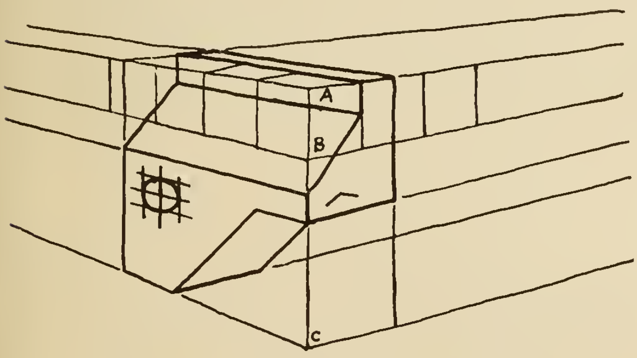


Figure 11-XVI. Box Construction

Another method of estimating distances which is often used is the line of sight method and is described as follows: Figure 12-XVI. Hold the clipboard or sketch pad perpendicular to the line of sight (from the eye to the object) and obtain the direction of a line on the sketch by holding the pencil at arm's length and parallel to the board. Rotate the arm until the pencil appears to coincide with a line on the model. From this position move the pencil back to the drawing, keeping it parallel to the position formerly obtained. Draw the line. Next, hold the pencil in a plane perpendicular to the line of sight; revolve as before, until the pencil appears to coincide with the line on the model; move the thumb along the pencil until the apparent length of line is laid off on the pencil. Rotate the hand back to the original position parallel to the line of the drawing. Hold the end of the pencil until it appears to coincide with the end of the line. Sight across the thumb until a point on the line is located, giving the estimated length sought.

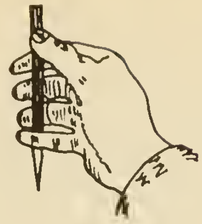


Figure 12-XVI
Estimating Distances

12-XVI. One-point Perspective. A very pleasing effect in pseudo-perspective is obtained by selecting oblique axes for the drawing, keeping the receding axis relatively flat, and slightly converging the receding lines, Figure 13-XVI, thus obtaining a one-point perspective. See Article 9-XVI.

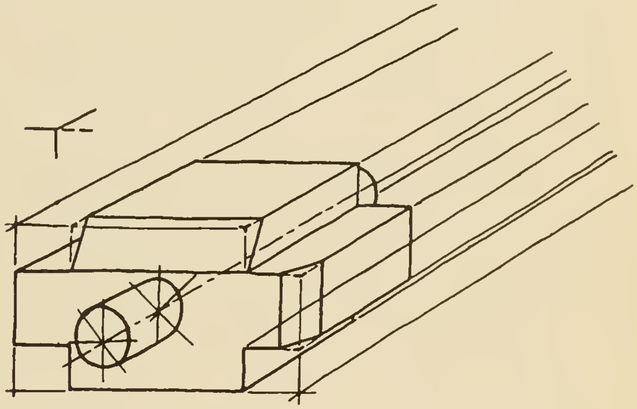


Figure 13-XVI. One-Point Perspective

13-XVI. Measurements. After the object has been studied and the necessary dimensions are decided upon, witness lines and dimension lines are placed on the drawing. The corresponding dimensions are taken from the object by making direct measurements with the tools described in Article 4-XVI. The drawing equipment should never be used for this purpose, as these implements are apt to be damaged. Measurements should be taken from finished surfaces if possible. When measuring rough castings care must be exercised so as not to include inequalities of foundry operations. Irregular curves can be dimensioned, as shown in Figure 5-XVI, by coordinate offsets. A beginner is apt to omit vital dimensions and other data. The sketch should not be cluttered with unnecessary dimensions, but it is better to have too many than too few.

14-XVI. Rules for Pictorial Sketching. When making a pictorial sketch, the following rules should be observed:

(1) Keep the receding axes flat.

(2) Keep parallel lines parallel except in the case of pseudo-perspective, when parallel receding lines should slightly converge.

(3) Keep isometric and oblique lines parallel to the corresponding pictorial axes.

(4) As a rule, sketch in boxes for the whole object, for the principal parts, for circles, and for ellipses.

(5) In isometric sketching, draw ellipses in the right vertical face so that the major axis slopes up and to the right. In the left vertical face draw the ellipse with the major axis sloping up and to the left. In the top or horizontal face, draw the ellipse with the major axis horizontal. See Figure 10-XVI.

(6) Do not draw dotted lines unless they are necessary for clearness.

(7) Place witness lines, dimension lines, and dimensions so they appear to lie in the same plane as the part being dimensioned.

(8) Use line shading sparingly. See Article 15-XVI.

15-XVI. Shade and Shadow Representation. Only two rectangular dimensions can be drawn in a plane surface. Since drawings are made in planes, the third dimension depth must be represented to the eye by some artificial means. When this is not done, there is too much flatness and it is too difficult to visualize the depth of an object which is perpendicular to the surface of the paper. Shades and shadows are used by artists and architects to bring the object into relief and thereby aid the eye in visualizing depth.

The engineer is not so much concerned with the above representations in obtaining the relief effect on his drawings. He omits shadows entirely and uses ruled lines to represent shading, called line shading. He seeks to obtain a contrast between surfaces, emphasizing some, suppressing others. He violates the strict principles of shading for simplicity. As a general rule (1) the surfaces perpendicular or nearly perpendicular to the line of sight are not shaded; (2) surfaces or parts of surfaces farthest from the observer receive the heaviest shading; (3) curving surfaces may be shaded with either straight lines or curved lines as illustrated; (4) a small amount of shading is more effective than a lot of shading--a contrast in surfaces is sought; (5) drawings which do not contain hidden outlines (dotted lines) should be treated with line shading. This applies to sectional views, assembly drawings, and pictorial drawings.

Figure 17-III illustrates the method of line-shading a sphere, and in many of the following illustrations methods of shading cylinders, cones, prisms, and other elementary structures can be found and should be studied. The principles can then be applied when shading the more complicated drawings. Numerous illustrations can be found in this chapter.

16-XVI. Pictorial Dimensioning. The general rules for dimensioning working drawings will apply here. (Some of the special rules will not.) In addition to the general rules, the following ones should be added for pictorial drawings:

1. Dimensions should be read from the lower center of the drawing.
2. A witness line or a dimension line should be drawn parallel to one of the pictorial axes.
3. A vertical style of lettering should be used.
4. All lettering should be placed so that it lies in the plane of the witness lines and dimension lines. To check this rule: A line sketched through the center of the letter or numeral should be parallel to the witness lines of that dimension. This will give the effect of vertical lettering, rule 3.
5. When convenient, dimensions may be placed on the face of the drawing.

The above rules should be checked in Figures 13-VI, 8-VII, 11-VII, 12-XIV, and 11-XV.

## EXERCISES

17-XVI. The student should choose the problem space and scale to be used and sketch the following problems free hand. When using pictorial representation, he should use the kind of pictorial sketch which will best represent the object. All sketches should be dimensioned.

An excellent exercise would be to study an object in exercise 1 or 2, Group 1-XVI, and then, after closing the book, sketch the object from memory.

### Group 1-XVI. Orthographic Sketching

1. Make an orthographic sketch of an assigned object of Figure 14-XVI. Furnish missing or invisible details.

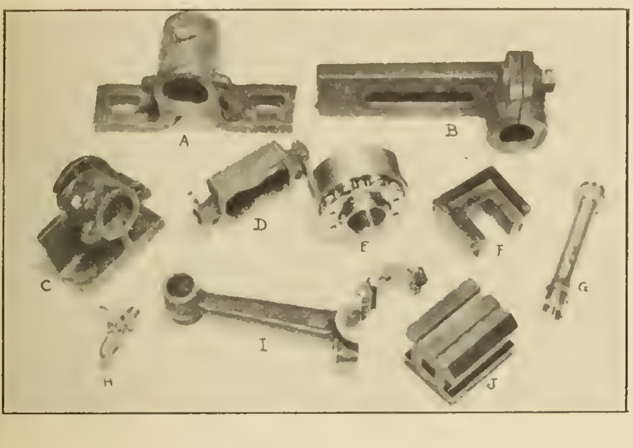


Figure 14-XVI. Models for Sketching

2. Make an orthographic sketch of Figure 6-XVI.

3-5. Make a pictorial sketch of Figures 3-XVI, 4-XVI, and 5-XVI.

6-18. Same as ex. 1-13, Gr. 1, Ch. XIV, except do free hand. The only equipment needed is a board, paper, soft pencil, and eraser.

19-33. Same as ex. 1-15, Gr. 4, Ch. XIV except do free hand. (See exercises 6-18, above.)

If this chapter were assigned before Ch. XIV, these exercises could be used as preliminary sketches for exercises 1-5, Gr. 4, Ch. XIV. In case this is done, the student should make a free-hand plate, check carefully, and then submit to instructor for approval. Using the free-hand plate, make a plate drawn with instruments. Rearrange the free-hand plate, if in so doing the instrument plate will be improved. Make a tracing.

34-48. Make a free-hand plate of an assigned object as outlined in exercises 19-33 above. Use the free-hand plate to make an instrument plate and a tracing as directed above.

### Group 2-XVI. Pictorial Sketching

1. Make a pictorial sketch of an assigned object of Figure 14-XVI. Furnish missing or invisible details.

2-18. Make a pictorial sketch of Figures 7-VII, 13-VII, 10-VII, 11-VII, 14-VII, 4-X, 5-X, 6-X, 5-XIV, 6-XIV, 8-XIV, 9-XIV, 18-XIV, 19-XIV, 3-XVI, 4-XVI, and 5-XVI. Use the type of pictorial which will best represent the object. Supply any missing dimensions or details.

### Group 3-XVI. Log Cabin Sketching in Pictorial

1-6. Make a pseudo-perspective free-hand sketch of the log cabin represented in the plan of Figures 11-XVII, 45-XVII, 46-XVII, 47-XVII, 48-XVII, and 49-XVII. See Article 8-XVII.

### Group 4-XVI. Log Cabin Sketching in Orthographic

1-6. Make orthographic free-hand sketches of the log cabin represented in the plan of Figures 11-XVII, 45-XVII, 46-XVII, 47-XVII, 48-XVII, and 49-XVII. Show plan, front and end elevations. See Article 8-XVII.

### Group 5-XVI. Model Sketching

1. Make orthographic or pictorial free-hand sketches (as assigned) of the model furnished by the instructor.

### Group 6-XVI. Miscellaneous Sketching

1-6. Make free-hand sketches of the log cabins as outlined in ex. 1-6, Gr. 7-XVII.

# CHAPTER XVII

## MISCELLANEOUS APPLICATIONS

1-XVII. The foregoing Chapters are presented as an outline of the fundamentals of Engineering Drawing. In addition to the material just offered, other topics are herein listed which are thought to be of value as exercises in drawing.

2-XVII. Intersection of Planes. The line of intersection between two planes is common to both planes. This problem is merely an extension of the problem of finding the piercing point of a line and a plane.

To determine the line of intersection between two planes: Find where two lines in the first plane pierce the second plane. These two piercing points lie on the desired line of intersection and therefore determine the line.

Given: Planes ABC and MNO, Figure 1-XVII. Required: The line of intersection, UR, between the two planes.

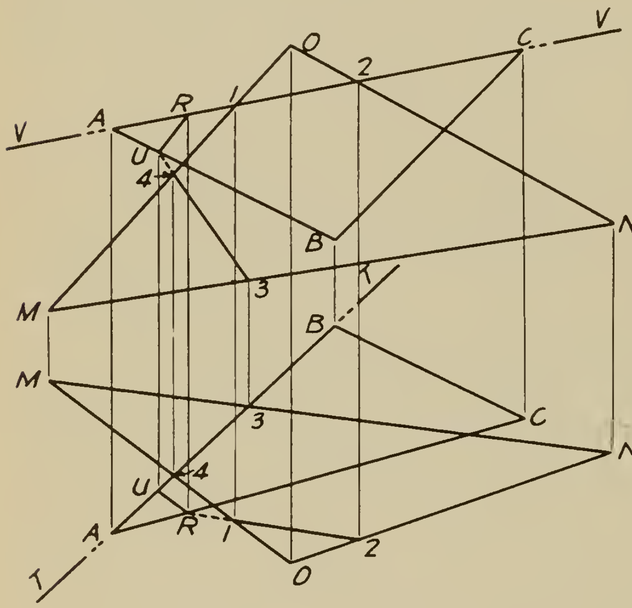


Figure 1-XVII. Intersection of Planes (Second Method)

Through AC (top view) erect the vertical plane V-V, and locate point R, the piercing point of AC and plane MNO. Through AB (front view) draw the receding plane T-T, and locate point U, the piercing point of AB and plane MNO. These two points, U and R, determine the desired line of intersection.

Another solution of the problem of this article is illustrated in Figure 20-XI. In this case the planes do not overlap in either view. The student should choose the method best adapted to the solution of his particular problem.

3-XVII. Line Making Specified Angles With a Horizontal and a Frontal Plane. If a line OP is to pass through point O and make an angle of H degrees with a horizontal plane, all possible lines thus drawn would represent the elements of a cone with vertex at O and base in TV, Figure 2-XVII (A). The base angle of the cone would be H degrees. If line MN, Figure 2-XVII (B), is to make an angle of F degrees with a frontal plane and pass through point M, it would therefore be an element of a cone with vertex at M, base in the frontal plane XY, and would have a base angle equal to F degrees.

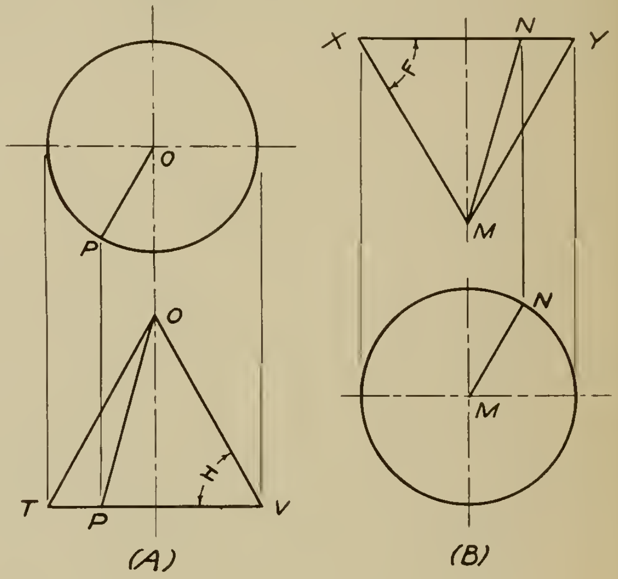


Figure 2-XVII. Line Making Specified Angle with a Horizontal or a Frontal Plane

If it is required to draw a line which makes an angle H with a horizontal plane and an angle F with a frontal plane, it will only be necessary to continue drawings (A) and (B), Figure 2-XVII, in order to locate the line. The procedure is represented in Figure 3-XVII and is described as follows:

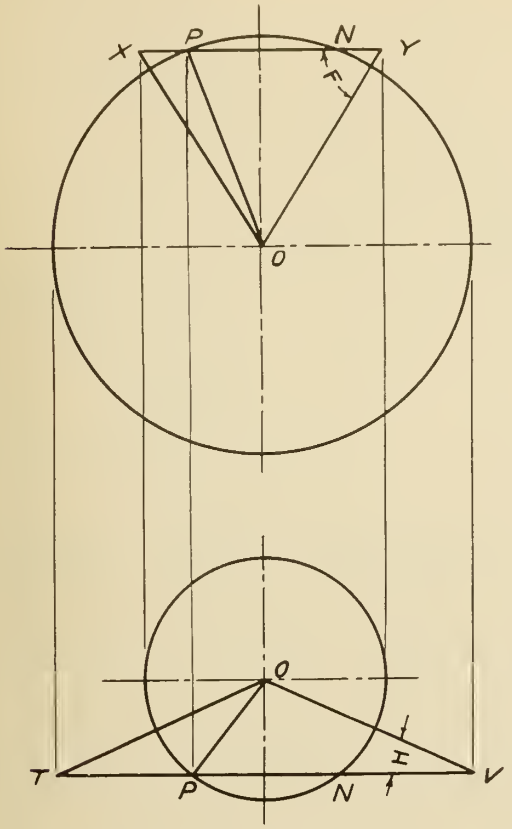


Figure 3-XVII. Line Making Specified Angles with Horizontal and Frontal Planes

Required: Line OP, which is to make an angle of H degrees with a horizontal plane and an angle of F degrees with a frontal plane, and is to pass through point O.

Procedure: Construct two cones with a common vertex O; base of one cone in the horizontal plane TV, with base angle equal to H degrees; and base of second cone in the frontal plane XY, with base angle equal to F degrees. Construct both cones with equal slant height. All points on the two bases will then be equidistant from the vertex. The two circles representing the bases of the cones will therefore intersect at P and N. The required line may now be drawn in eight different positions and four different directions. Line OP is in one of the positions and is therefore one of the lines of intersection of the cones.

The student should locate lines in the other positions as a check. The sum of the specified angles, H and F, will be less than 90 degrees. Why?

4-XVII. Angle between a Line and an Oblique Plane. The angle between a line and a a plane is seen in true size when the line is shown in true length and the plane is shown as an edge view, as illustrated in Figure 4-XVII, the direct method. But the indirect method of Figure 23-XI is considerably shorter.

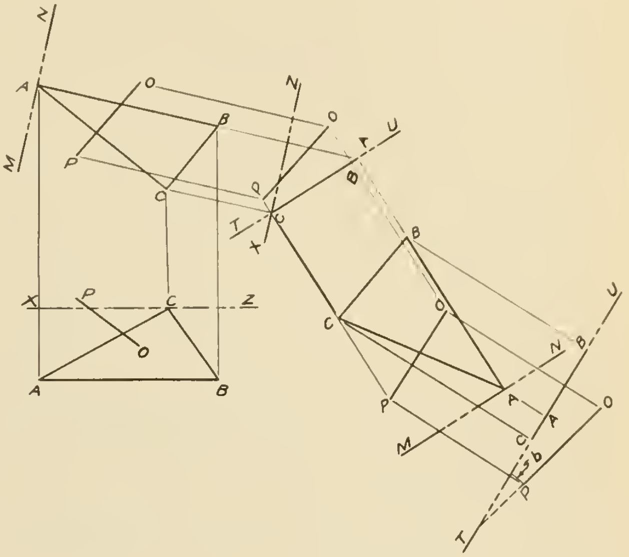


Figure 4-XVII. Angle between a Line and an Oblique Plane (Direct Method)

Procedure for direct method: Obtain an auxiliary view of the system showing ABC as an edge view. Draw a second auxiliary taken at right angles to ABC in the previous view. The plane will be shown as a normal view. From the second auxiliary, take a third auxiliary at right angles to line PO. In this last view the plane will again be seen as a line, and PO will be in true length. The desired angle, b, can now be measured directly.

5-XVII. Plane Making Specified Angles with a Horizontal and a Frontal Plane. It is required to draw a plane MNO, Figure 5-XVII (A) on the following page, through point O, making an angle of H degrees with a horizontal plane XY, when O and XY are given.

Procedure: Through O draw a horizontal line (level in the front view) and perpendicular to XY in the top view. Locate O in the auxiliary elevation. Through O in the auxiliary, draw a line making an angle of H degrees with XY. Locate M at the intersection of XY and the line just drawn. Select N at some convenient point on the line. Line MNO is an edge view of the desired plane. To obtain the front view of the plane: Draw rays from the auxiliary to the front, perpendicular to XY. Select M and N on their respective rays at a convenient point in the top view. Connect M, N, and O. Locate P at the intersection of ray O and line MN. Since two views of MNO are now determined, the front view can easily be drawn.

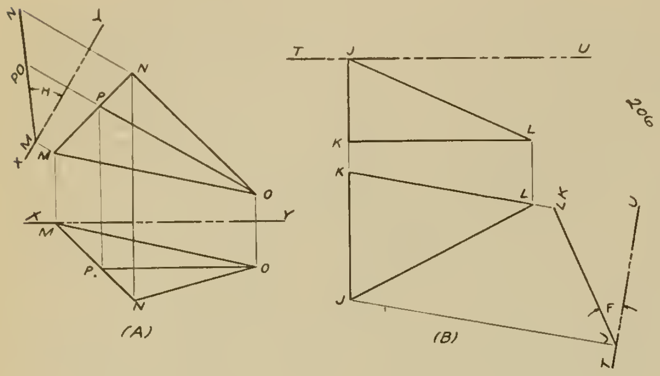


Figure 5-XVII. Plane Making Specified Angle with Horizontal or Frontal Plane

It is required to draw a plane JKL, Figure 5-XVII (B), through point L, making an angle of F degrees with a frontal plane TU, when L and TU are given.

Procedure: Through L draw a frontal line KL (level in the top view) and perpendicular to TU in the front view. Point K is located at any convenient place on the line. Locate LK, a point, in the auxiliary right. Through LK in the auxiliary, draw a line making an angle of F degrees with TU. Locate J at the intersection of the line just drawn and TU. Line JLK is an edge view of the plane. From J in the auxiliary, draw a ray perpendicular to TU. Locate J in the front view at any convenient place on the ray just drawn. Complete the top view.

To draw an oblique plane which passes through a given point, make an angle of H degrees with a horizontal plane, and an angle of F degrees with a frontal plane: The pictorial drawing of Figure 6-XVII (A) represents the solution of the problem--as shown in drawing (B). Analysis (see drawing (A)): Given, the frontal (vertical) plane JTU, horizontal (level) plane LTU, and point C. Required, plane JKL which passes through point C and makes an angle H with LTU and an angle F with JTU. Procedure: Through C draw a line DG making angles h and f with the level and vertical planes, respectively, which are the complements of the required angles H and F, i.e., $h = 90^{\circ} - H$ and $f = 90^{\circ} - F$. Through point C construct a plane JKL, perpendicular to DG, which is the required plane.

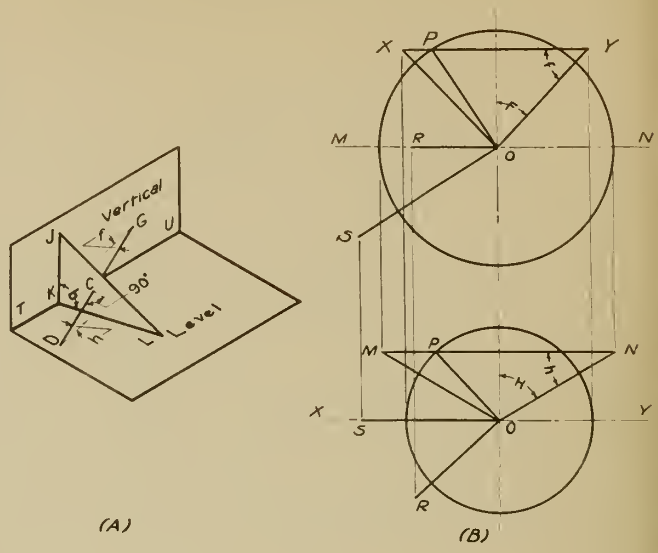


Figure 6-XVII. Plane Making Specified Angles with Horizontal and Frontal Planes

Solution (see Figure 6-XVII (B)): Through point O draw a line OP which makes an angle H with a horizontal plane and an angle F with a frontal plane, as outlined in Article 3-XVII. Point O and the horizontal and frontal planes are given. Construct the horizontal line, OS, perpendicular to OP. Draw the frontal line OR perpendicular to OP. See Figure 14-XI. Plane SOR is perpendicular to OP by construction and makes the required angles with the given planes.

It is possible to locate four different planes which will satisfy the above conditions, since OP can be drawn in four different directions. See Article 3-XVII. The sum of the angles which an oblique plane makes with a horizontal and a frontal plane must lie between 90 and 180 degrees. Why?

It is sometimes necessary to draw lines or planes in specified directions when designing automobile bodies, airplane fuselage or pontoons, or when laying out boat surfaces. Also, these problems are occasionally useful in setting up tangent planes. See Articles 14-XVII and 15-XVII.

6-XVII. Angle between Two Oblique Planes. A plane drawn perpendicular to two given intersecting planes will be perpendicular to the line of intersection of the given planes.

The angle between two planes is usually referred to as the dihedral angle.

The pictorial representation of two

intersecting planes is illustrated in Figure 7-XVII (A). A cutting plane is passed perpendicular to the two given planes and is therefore perpendicular to their line of intersection, HL. The angle, a, between the lines of intersection of the cutting plane and the two given planes, is the obtuse angle of the planes. The acute angle is usually given and may be expressed in this case as b = 180-a.

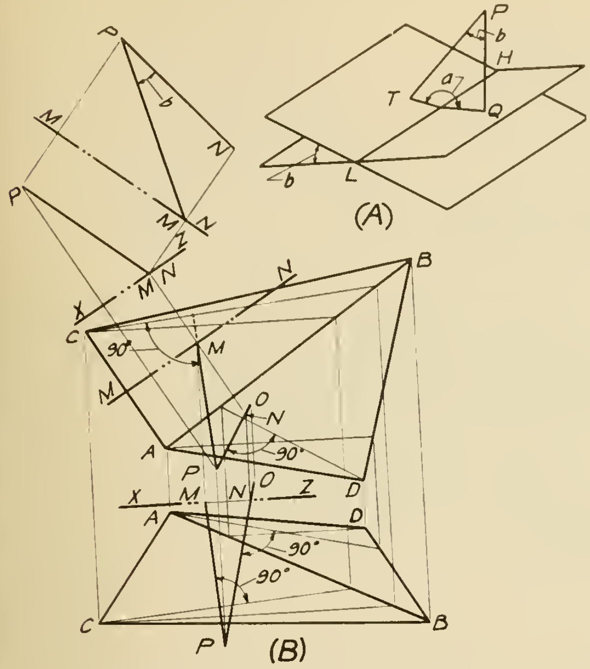


Figure 7-XVII. Angle between Two Oblique Planes (Indirect Method)

Procedure for indirect method, Figure 7-XVII (A): Assume a point, P, in some convenient location. Through P, erect two lines, one perpendicular to each of the two given planes, PT and PQ. The angle, b, between these two lines is the desired angle.

Given: Planes ABC and ABD. Required: The dihedral angle, b, Figure 7-XVII (B).

Assume point P in a convenient location. Erect PM perpendicular to ABC. Erect PN perpendicular to ABD. Draw an auxiliary elevation showing plane MPN as an edge view as indicated. Draw an auxiliary oblique showing MPN as a normal view. Measure angle b, which is the desired angle.

7-XVII. Framing a Hip and Jack Rafter. When a wooden structure is built, the timbers are usually cut to "fit in place" at the shop or on the ground and are to be assembled in place and fastened by nailing or by other means. This is called "timber framing." Structural drawings should show the angle of cut, lengths, and size of the various members.

Figure 8-XVII (A), on the following page, is a line drawing of a hip roof. The terms shown are self-explanatory. As previously stated, the pitch of a roof is equal to the rise divided by twice the run. Drawing (C) shows the method of obtaining the angle of cut and length of a common rafter.

To obtain the angle of cut when the pitch is one-third: On the tongue of the carpenter's square, CM, place the 8-inch mark on the edge of the rafter at C. Then place the 12-inch mark of the body of the square, d, on the same edge of the rafter, as indicated. Mark the rafter along CM. The pitch will be 8/24 or 1/3. The length of the rafter is determined from tables on the face of the square, or obtained by measuring diagonally with the square. The lower end of the rafters is never cut to a feather edge. It is allowed to extend past the edge of the sill and is cut off flush with the wall. The length of cut in the vertical face is usually taken as one-half the thickness of a rafter, as illustrated.

To find the angles of cut of a hip rafter: Obtain a normal auxiliary elevation, part (B), of the rafter. The angle due to the rise, F-1-3, will be seen in true size. Obtain an edge view of the rafter taken from the auxiliary elevation. The angle due to the run, F-1-2, will be seen in true size.

To find the angles of cut of a jack rafter: Draw an end elevation (a normal view) of the jack rafter. The jack rafter, hip rafter, and ridge pole are shown in this view. Proceed as directed above in the framing of a hip rafter. The angles of cut are indicated.

8-XVII. Architectural Drawing. A general knowledge of architectural working drawings is important to engineers, especially to structural engineers. It is beyond the scope of this book to take up architectural designing. However, it might be desirable to introduce a few of the more elementary architectural drawings to supplement the structural drafting already presented. Log cabin design, due to general interest in this type of building construction, is used as a means of introducing a few exercises in architectural drawing.

Much of the material for this article was obtained through the courtesy of the Department of Agricultural Engineering, University of Idaho, especially the detail features of Figures 12-XVII and 13-XVII. The original sketch and plan of the cabin of Figure 9-XVII were prepared by the Department of Agricultural Engineering, University of Arkansas,

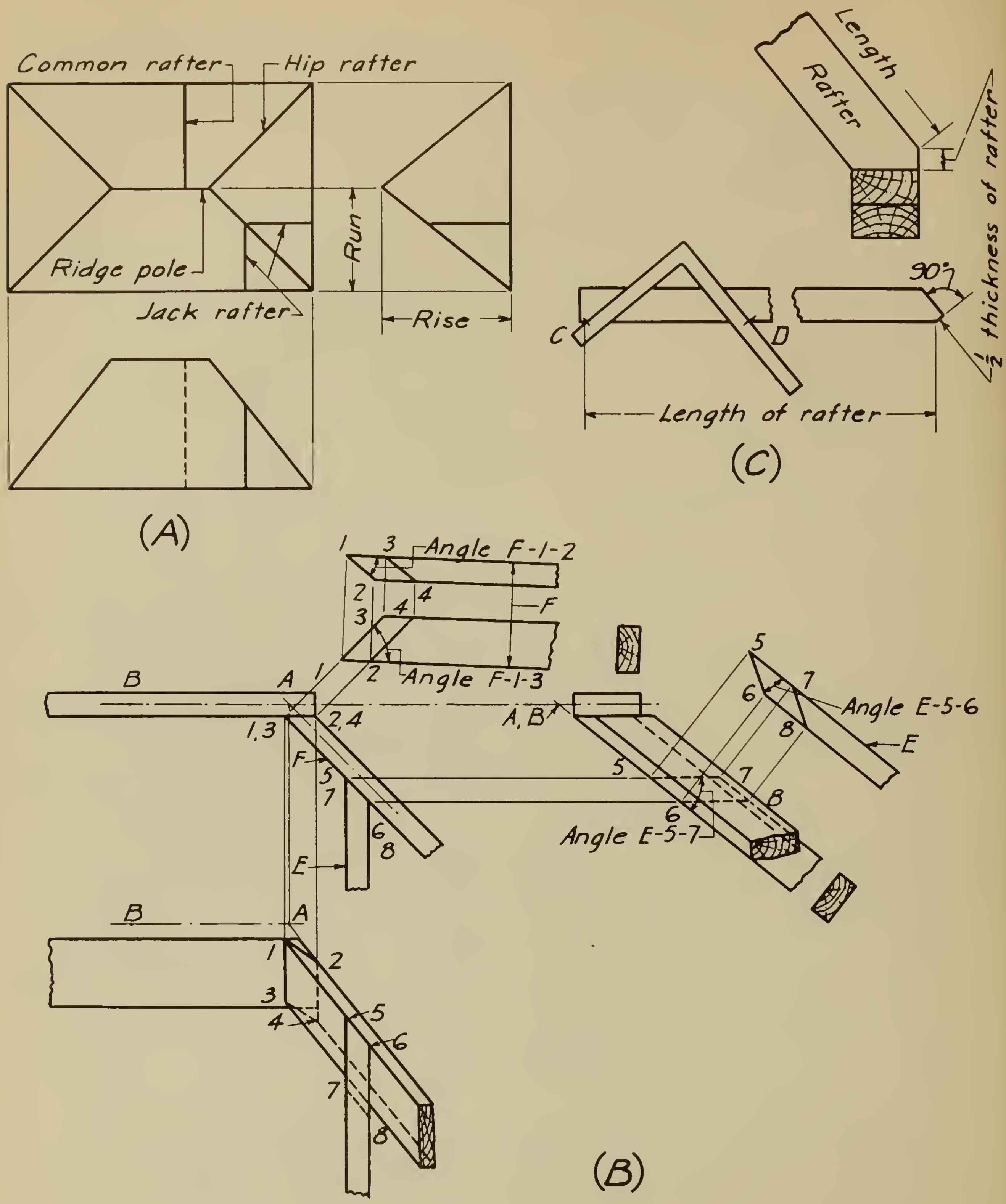


Figure 8-XVII. Framing a Hip and Jack Rafter

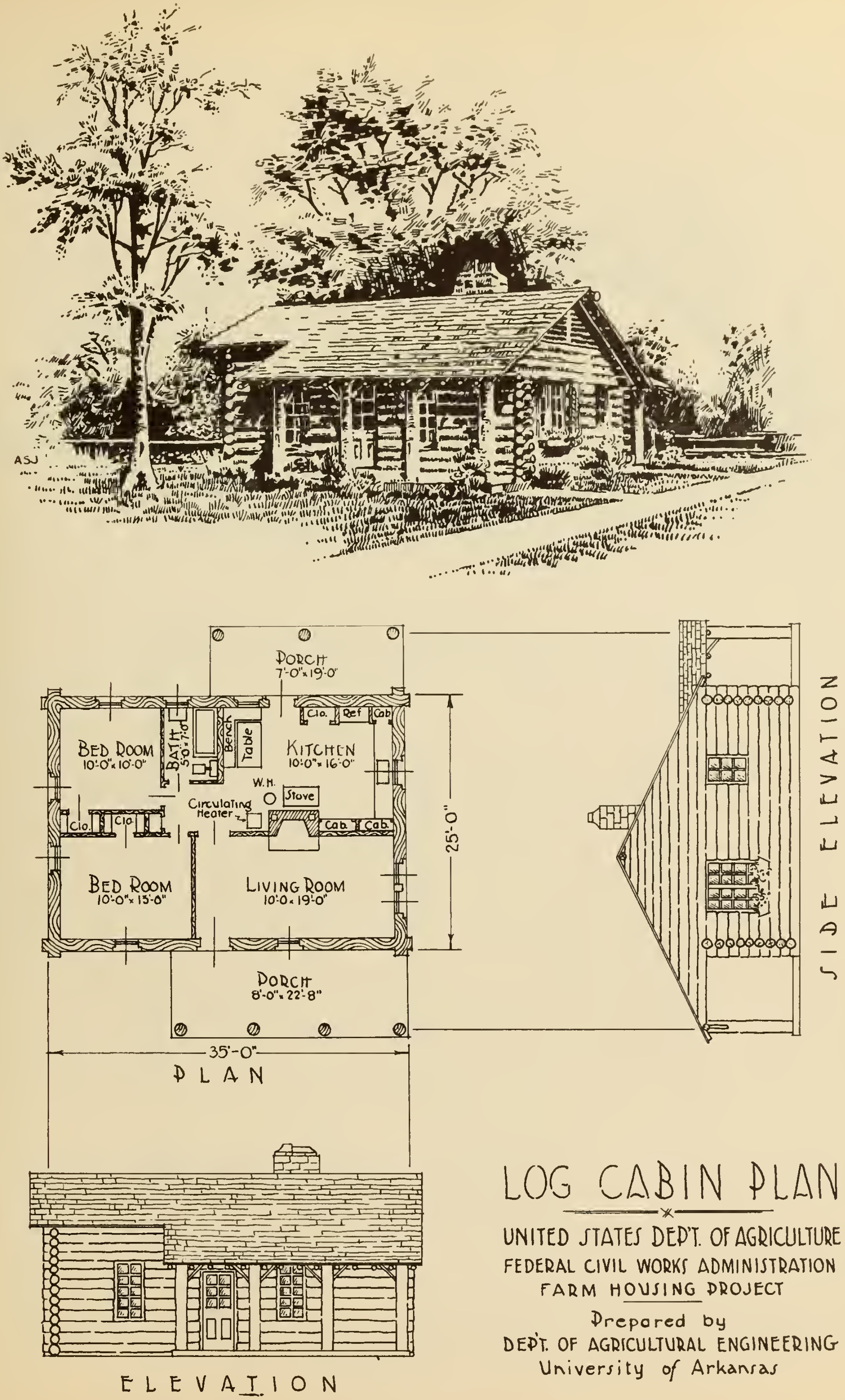


Figure 9-XVII. Plan and Elevations of a Four-Room Log Cabin

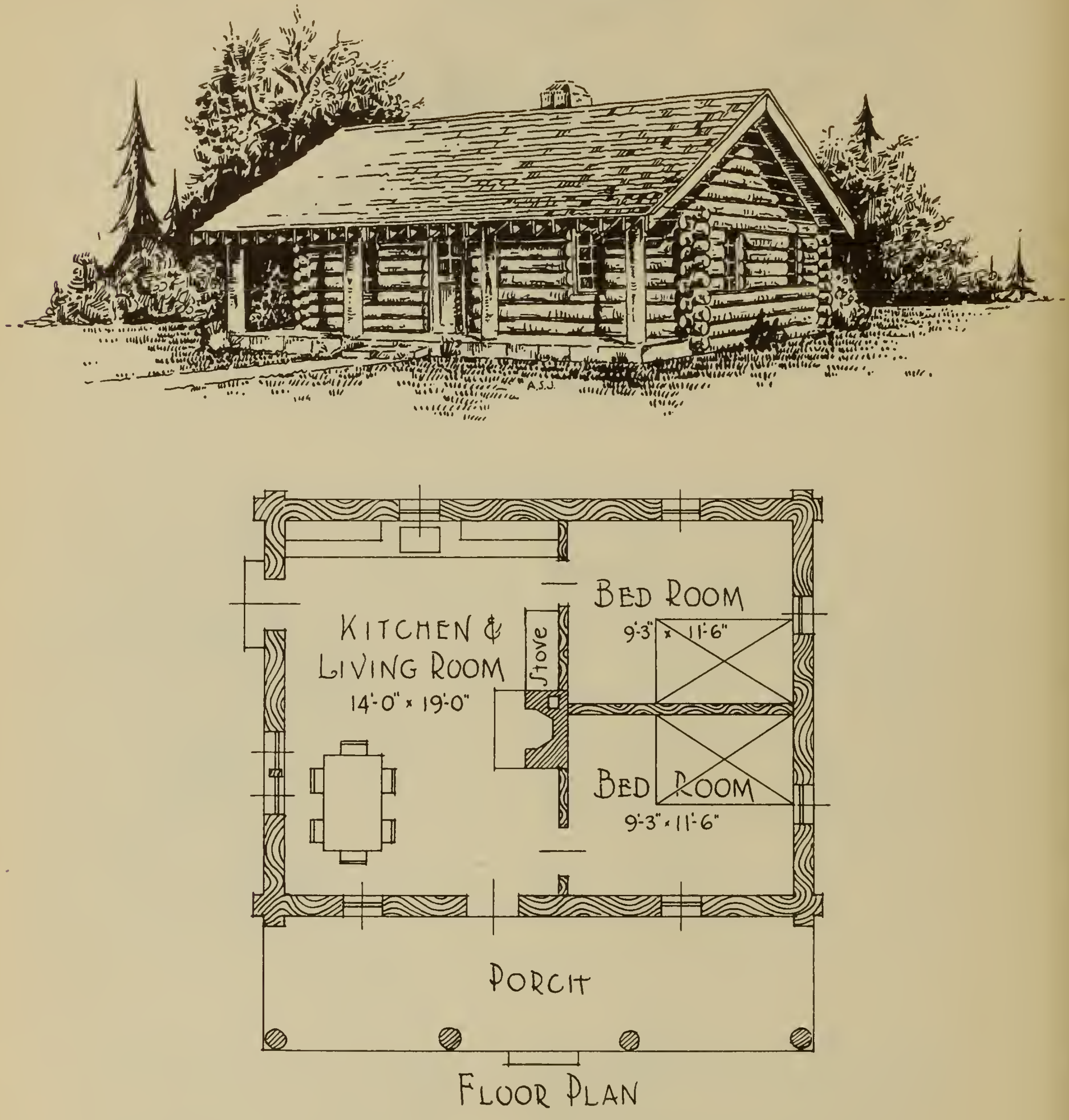
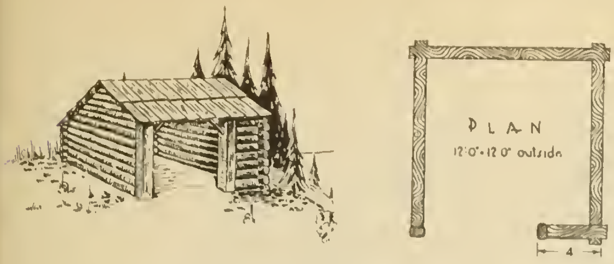


Figure 10-XVII. Plan and Pictorial Elevation of a Three-Room Log Cabin



BILL OF MATERIAL

| Name | Material | Reqd. |
|---|---|---|
| 10"•14'0" Logs | Lodge Pole | 30 |
| 6"•14'0" Logs | Lodge Pole | 7 |
| ½"•8"•36" Shakes | Cedar | 220 |
| 6d. Nails | Wire | 3 lb. |
| 60d Spikes | Wire | 10 lb. |

Figure 11-XVII. Plan and Pictorial Elevation of an Overnight Shelter

through the United States Department of Agriculture. The draftsman's attention is called to the architectural lettering of Figure 14-XVII. This style of lettering should be used on all architectural drawings. A bill of material, Figure 11-XVII, should be furnished with each exercise of this article.

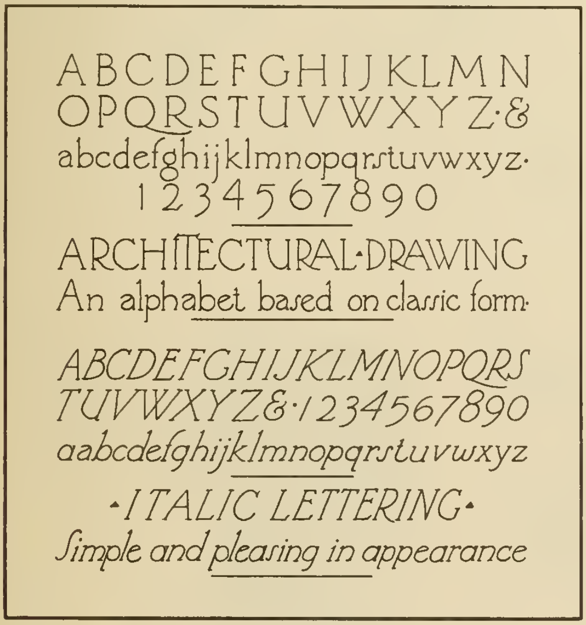

ABCDEFGHIJKLMN
OPQRSTUVWXYZ·&
abcdefghijklmnopqrstuvwxyz·
1234567890
ARCHITECTURAL·DRAWING
An alphabet based on classic form·
ABCDEFGHIJKLMNOPQRS
TUVWXYZ&·1234567890
aabcdefghijklmnopqrstuvwxyz
·ITALIC LETTERING·
Simple and pleasing in appearance

Figure 14-XVII. Architectural Lettering

9-XVII. Vectors. Quantities which have both magnitude and direction are called vectors. Such a quantity can, therefore, be represented by a straight line with a length equal to the size of the quantity and the direction equal to the direction of the line of action of the quantity.

If a body is displaced from A to B, Figure 15-XVII, and again from B to C, then, a-c, the resultant displacement, is called the vector sum of the two displacements a-b and b-c.

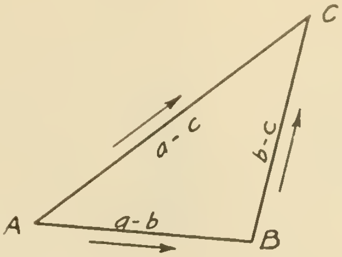


Figure 15-XVII. Vector Diagram

A body is moving with uniform velocity in a certain direction. In time it will describe a distance s, i.e., s = vt. Such a quantity, when the direction is known, can be represented by a vector. Velocity is a relative quantity. One body moves with respect to another body. For instance, consider a man on the deck of a boat moving with a velocity of 2 miles per hour, Figure 16-XVII, relative to the boat. The boat is moving through the water with a velocity of 15 miles per hour relative to the water, and the water is flowing over the earth with a velocity of 5 miles per hour. When the directions of the various velocities are known, the velocity of the man with respect to the earth, a-d, can be determined as illustrated.

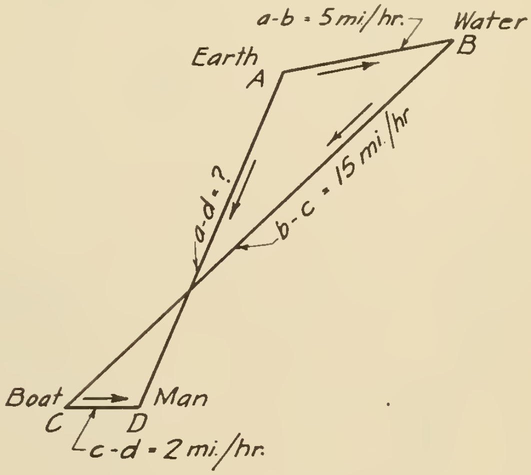


Figure 16-XVII. Velocity Diagram

A force, which tends to change the state of motion of a body, is conceived as a push or a pull applied to a body at a definite point and in a definite direction. If at rest, such a push or pull tends to move the body, but motion may be prevented by the

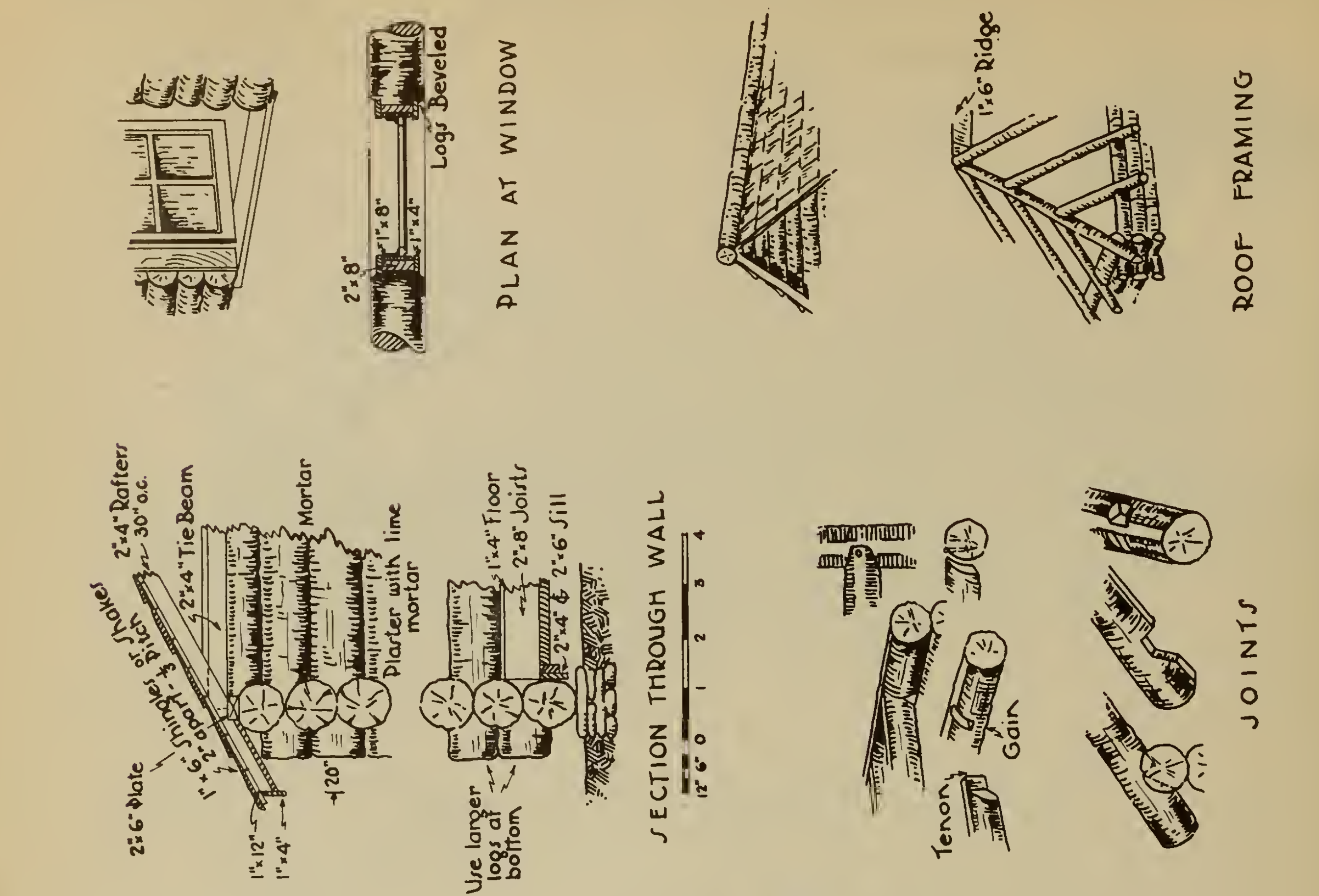


Figure 13-XVII. Log Cabin Detailing

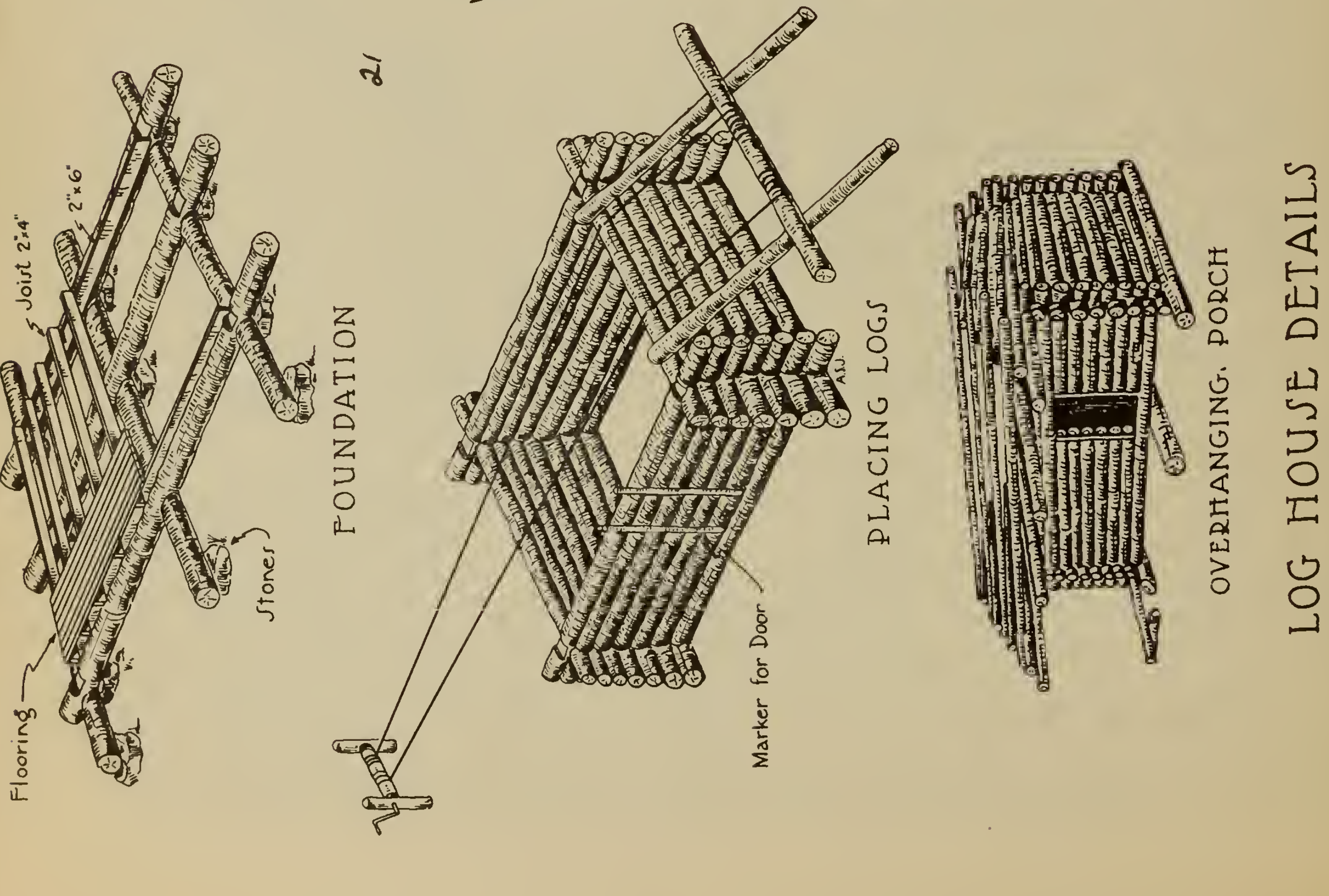


Figure 12-XVII. Details of Log Cabin Construction

action of other forces. Such a system of forces is said to be in equilibrium. The effect of a force is completely determined when the following are known: (1) Magnitude, (2) direction, and (3) point of application. The line of action is parallel to the direction of the force and contains the point of application. Since a force can be represented by a vector (straight line), the magnitude of the force can then be measured along the line of action. The unit force is the pound, arbitrarily chosen, and is not to be confused with the pound mass.

Forces acting at the same point are concurrent. If the lines of action all lie in the same plane they are coplanar. If the lines of action are not all in the same plane they are noncoplanar. A single force which is equivalent to a given system of forces is called the resultant of that system. The equilibrant is that force which will hold a system in equilibrium. It is equal to the resultant in magnitude, is opposite in direction, but they must have the same point of application.

A system of concurrent, coplanar forces cannot be solved if more than two forces are unknown.

A graphic resolution of the system of forces acting in a Warren truss with 4 panels is shown in Figure 17-XVII. Bow's system of notation is used in lettering the vector diagram. In this system each space (area) in the frame is given a numeral. Each space between external forces or between an external force and the frame is given a capital letter. An arrow is drawn to indicate the way these forces are acting, and they should be taken in order (clockwise or counterclockwise) around a joint or pin. A force acting toward a joint--see free body diagram--is in compression. If acting away from a joint it is in tension. At joint $U_1$ the force acting in member 1-2 indicated in the free body diagram is shown as vector A-2 in the vector diagram. Since there are four characters and only three vectors, the character 1 is omitted in the vector diagram. In a graphical resolution of forces referred to alone, there must be three systems of drawings showing (1) the space drawing, (2) the free body diagram, and (3) the vector diagram. Since there are 4 panels, three forces, P, will act at the joints, indicating the dead load. The reactions, R, will each equal 1 1/2 P. The joints are taken one at a time, in the order shown, and a free body diagram sketched to show the direction of each force. (It should be noticed that the top chord is in compression and the lower chord in tension.) A vector diagram is then drawn, in the order stated, with each vector parallel to the force which it represents. These forces are shown in the free body diagram, and they are there parallel to the members of the truss in which they are acting. A push is a compression force, and a pull is a tensional force. The magnitude of each force can now be scaled from the vector diagram. Arrows should all have the same order of direction around the diagram if the joint is to be in equilibrium. So far, only coplanar forces have been considered, but the same principles apply in the case of concurrent, noncoplanar forces. It should be borne in mind, however, that in dealing with noncoplanar forces (1) three dimensions must be employed, (2) only true length lines can be scaled, and (3) at least two views will be required in the space drawings and vector diagrams. A system containing one known force and three unknown forces can be solved when one of the views in the space drawing shows a plane containing two of the forces as an edge.

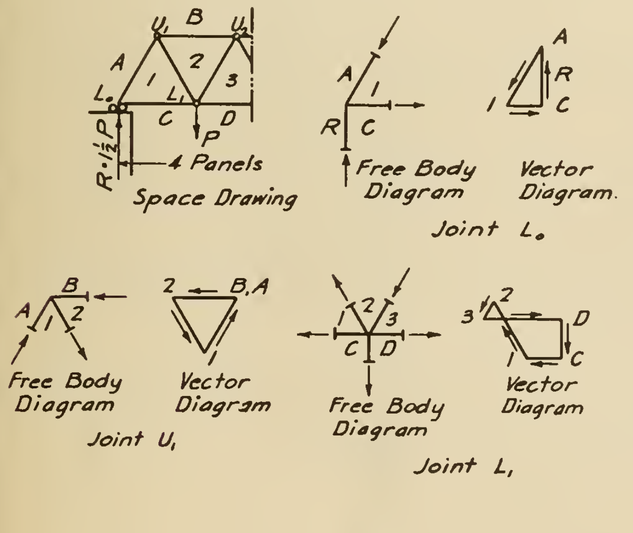


Figure 17-XVII. Forces Acting in a Warren Truss

A tripod, Figure 18-XVII on the following page, has a force of 1000 pounds acting downward at A. A two-view space drawing is required. The free body diagram, in this case refers to the front view rather than the top. Bow's notation is placed on the free body diagram and the front view rather than the top view. Since two members, AC and AD, coincide in the front and free body diagram, one of the members, AD in this case, is bent to one side so as to show space 1. The direction of the member remains unchanged. Two views of the vector diagram are next drawn.

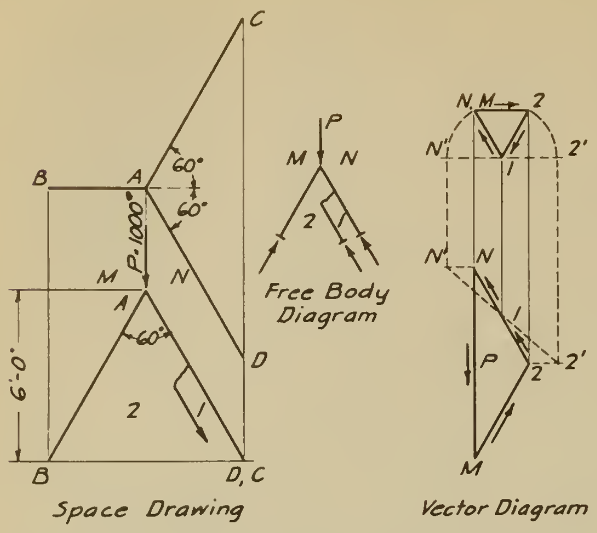


Figure 18-XVII. Concurrent, Noncoplanar Forces

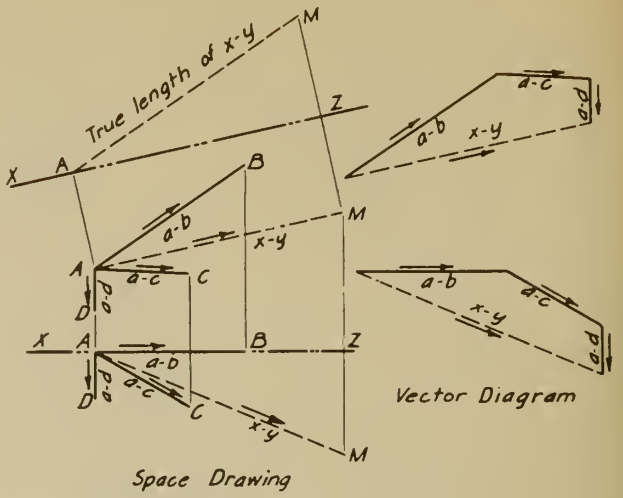


Figure 19-XVII. Resultant

Force MN is seen as a vertical line in the front and is a point in the top view--as indicated by the free body diagram and the front and top views of the space drawings. Vector M2 is drawn in the front view parallel to N2 in the free body diagram. Vectors N1 and 1-2 have the same direction. So, from N draw a line parallel to N1 in the free body diagram. The intersection of the line just drawn and vector M2 will locate point 2. Point 1 lies on N2, and its exact position will be determined later. From point MN in the top view draw vector M2, a level line since it is parallel to AB in the top view of the space drawing. Point 2 is on this level line and directly above 2 in the front view. Vector N1 is drawn parallel to line AD in the top view of the space drawing, and vector 2-1 is drawn parallel to AC in the top of the space drawing. The intersection of these two vectors will locate point 1 in the top view of the vector diagram. Point 1 can now be located in the front view on line N2. Vectors N1 and 1-2 are now revolved into true length in the front view, which gives the value of the forces acting in AD and AC, respectively. The force acting in AB is represented in true length in the front view of the vector M2. The amount of these forces in pounds, preceded by C or T, depending on whether they are in compression or tension, is placed on the corresponding members in the top view of the space drawing.

The space drawing of Figure 19-XVII represents a system of three forces acting on a body at point A. Evidently, the system is not in equilibrium. The vectors in this case represent velocities with a resultant movement of the body with respect to point M, which is in the direction x-y. It is evident, then, that the entire system could be replaced by the vector x-y without changing the conditions under which the system is operating. Vector x-y is called the resultant. If the direction of the resultant were reversed --the magnitude remaining the same--vector x-y would become the equilibrant. It would be that force which would hold the system in equilibrium.

To draw the resultant of a system of concurrent, noncoplanar forces:

Given: Forces AB, AC, and AD acting on a body at A as indicated in the space drawing of Figure 19-XVII. Required: The magnitude and direction of the resultant.

Draw the vector diagram for the front view. The polygon will not close, since the system is not in equilibrium. The vector x-y, will close the polygon and, acting in the direction of the other vectors, will give the direction and foreshortened length of the resultant in the front view. Draw the vector diagram for the top view, as drawn for the front view. Point M in the front and top views should fall on the same vertical line. The true length of AM gives the magnitude of the resultant, as indicated in the auxiliary elevation view.

Many engineering problems are solved graphically by means of vectors. Some outstanding examples are the determination of stresses in bridges, roof trusses, steel mill buildings, and other problems covered in graphic statics. Three-dimensional vector diagrams may be used in the solution of electromagnetic problems, problems in space travel of machine parts treated in the subject on mechanism, and problems relating to rates, moments, and the like which are represented by quantities acting in different planes. The graphical solution is faster, in most cases, than the analytical, and with proper care should be sufficiently accurate.

10-XVII. Mining Problems. Engineers in the various fields of the profession are likely at one time or another to meet with certain problems relating to mining and geological engineering. Many of the problems can readily be solved by certain graphical methods. Some of these solutions employ certain fundamental geometrical operations which are given in this article and are to be supplemented with similar solutions presented in Chapter XI.

Definitions. In addition to the mining terms employed in Chapter XI, the following definitions are to be added: The surface of loose material, when dumped, conforms roughly to the surface of a cone. The angle of repose of the material is the base angle of the cone so formed. Veins of ore, when appearing at the surface of the ground, are called outcrops, having been exposed by surface erosion. A shoot is a rich streak of

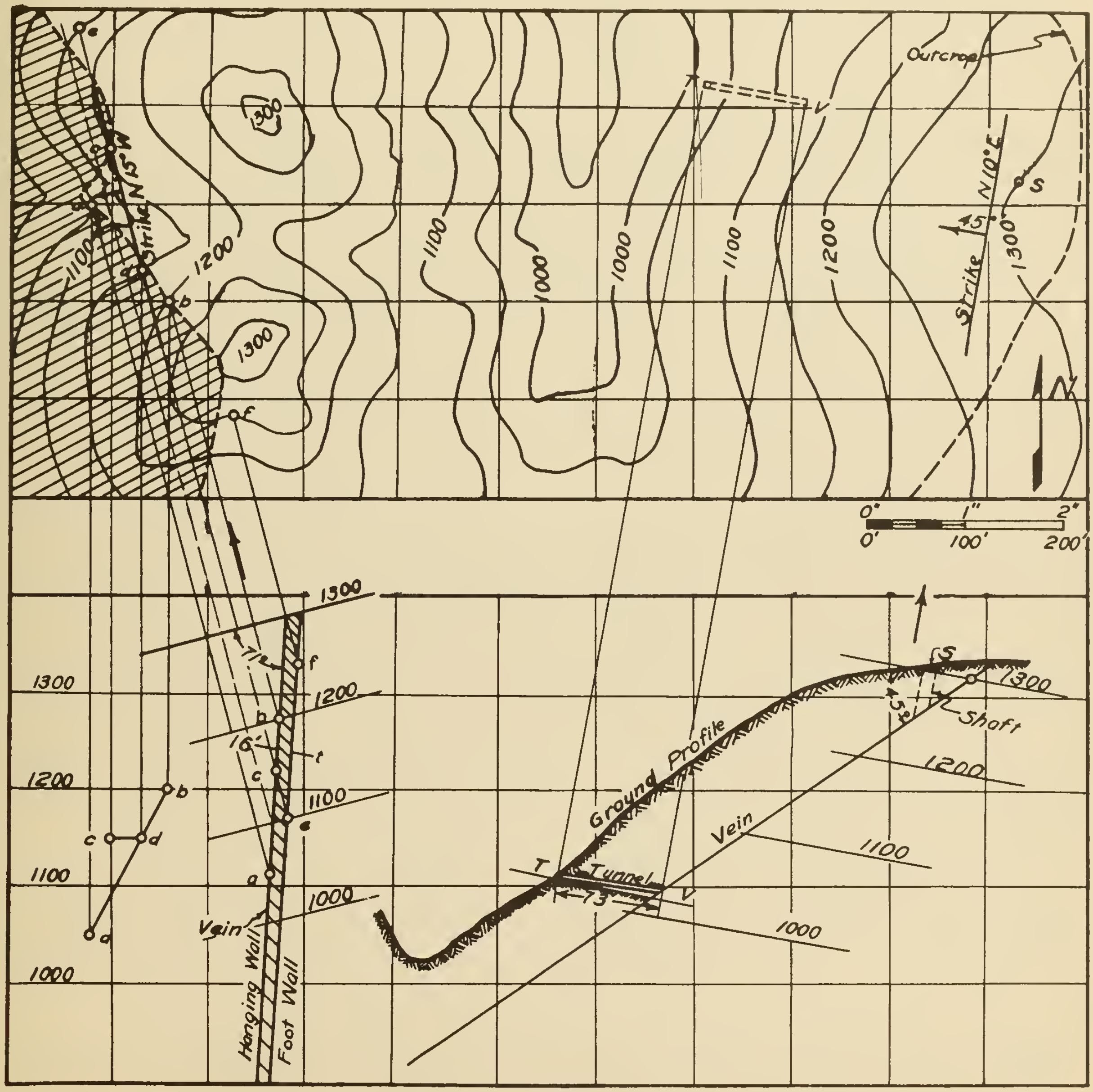


Figure 20-XVII. Tunnel and Vein Location

ore in a vein. A tunnel is a horizontal, or nearly horizontal, passage extending across the country rock to a vein and having one opening at daylight. A vertical, or nearly vertical, opening from the surface of the ground to a vein is called a shaft. An entry which follows the dip of a vein or seam is called an incline. A drift is a horizontal passage lying in a vein. The lower surface of a vein is called the foot wall; the upper surface is called the hanging wall.

To Locate the Strike and Dip: Obtain a map of the location, Figure 20-XVII, and locate points in both walls of the vein, i.e., a, b, and c in the hanging wall; and e and f in the foot wall. Draw any horizontal line in either wall of the vein, as line cd in the hanging wall. The strike is the bearing of this line on the map (N 15° E). In the edge view of the vein, locate lines representing elevations of 1000 ft., 1100 ft., etc. The dip is the angle either wall of the vein makes with one of these lines of elevation (71° westward).

To Locate the Line of Outcrop: In the edge view of the vein, select points in the hanging wall at known elevations, as the 1200-ft. elevation. Draw rays projecting back to the plan (map). Where the ray crosses the 1200-ft. contour will be found two points of outcrop. Likewise, project back from the 1100-ft. contour. Three points are

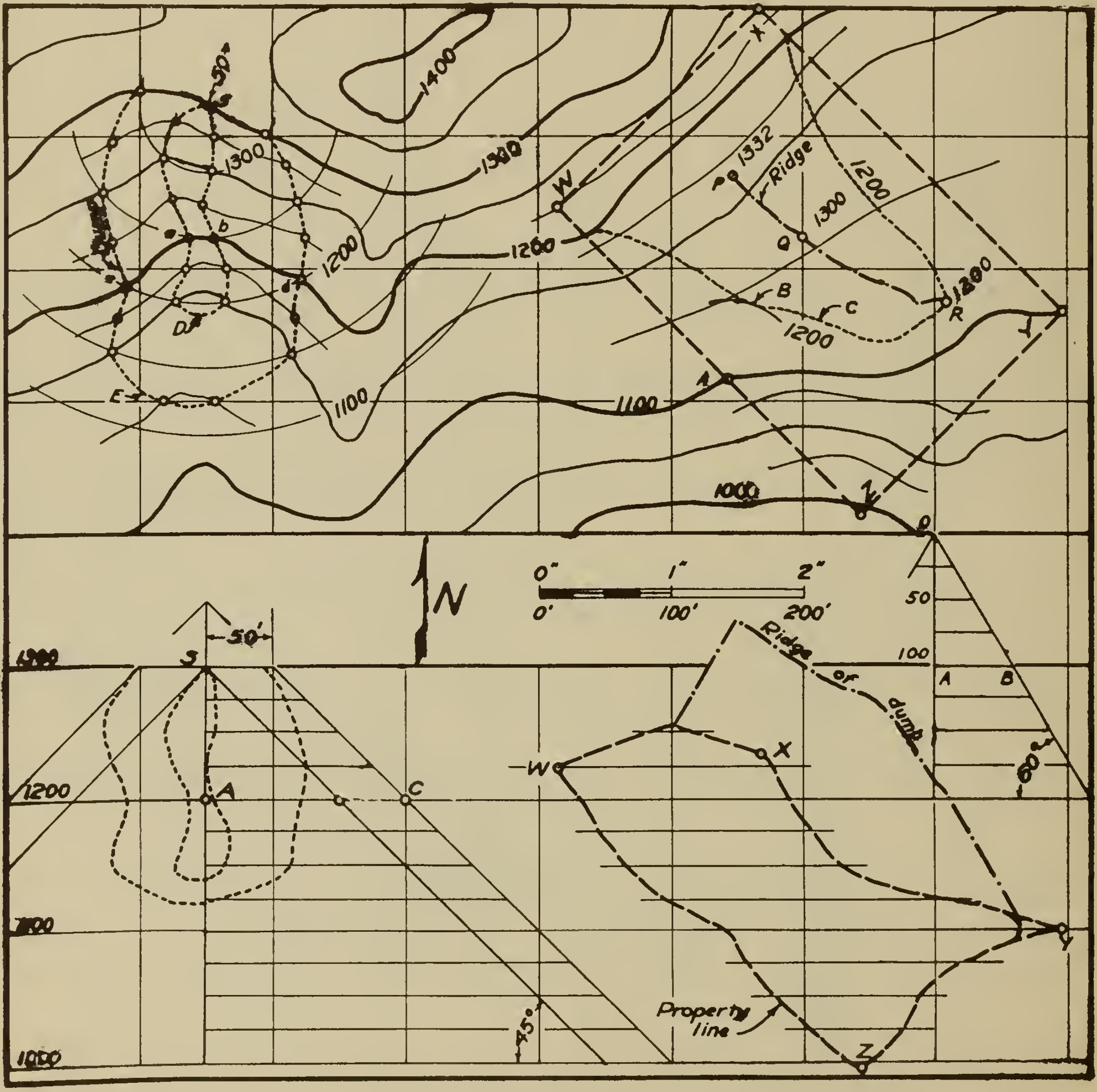


Figure 21-XVII. Mine Dump Problems

thus located on the 1100 ft.-contour. A sufficient number of points so located will determine the line of outcrop. It will probably be necessary to interpolate between contours.

Shaft and Tunnel Location. A shaft S and T are located on the eastern portion of the map. Also there is indicated the outcrop, strike, and dip of a thin vein. A vertical shaft is located at S. The shaft is approximately 50 feet deep. The tunnel is to be started on the 1020-ft. contour at point T. It is to be constructed on a 6% upgrade so that good drainage can be secured. Also, loaded cars will roll out of the mine. The location of the tunnel is at right angles to the strike, which will provide the shortest possible length on this grade. Length of tunnel is 73 feet.

To Locate a Mine Dump: The extent to which a mine could be worked might possibly be limited by the boundary of the property upon which the refuse of the mine is to be dumped. It is therefore necessary at times to determine the outline of the dump before mining operations are begun.

The mouth of a shaft is located at S, Figure 21-XVII, on the 1300-ft. level. The angle of repose of the muck is 45°. To find the line of intersection between the cone so formed and the canyon wall: Use horizontal cutting planes. Arbitrarily choose a datum plane from which to work. A plane at the 1200-ft. elevation is chosen. The 1200-ft. cutting plane will cut a circle from the cone with radius AB; see front elevation. The plane will intersect the ground surface on the 1200-ft. contour. Locate points of intersection a and b on the 1200-ft. contour (see map) by sweeping an arc of radius AB with center at S. By using a series of cutting planes at different elevations, outline D of the dump is formed. It will be necessary to interpolate between contours.

When the vertex of the dump is located at the mouth of the shaft S, the outline D of the dump is materially limited. It was decided to increase the size of the dump by dumping material at the 1300-ft. elevation at increasing radial distances from S until a flat surface is formed around the mouth of the shaft. The maximum permissible outline E of the dump was reached when the radius of dump was 50 ft., center at S. To locate the outline E: Construct the frustrum of a cone in the front elevation, radius of the upper base equal 50 ft. The radius of the dump at the 1200-ft. elevation is now equal to AC. Sweep an arc on the map with center at S and radius equal to AC. Two points c and d on the 1200-ft. contour are thus located. Other points on the dump outline are located by establishing cutting planes at different elevations.

A mining claim WXYZ is located on the eastern part of the map of Figure 21-XVII and material to be dumped is brought to the surface on the 1350-ft. contour. A ridge PQR is to be located along which material is to be dumped so that the outline of the dump will just come down to the property line. The angle of repose of the material is 60°. The cone of the dump is constructed in the front elevation. To locate the ridge PQR: Arbitrarily choose a datum plane from which to work. A plane at the 1200-ft. elevation was chosen. Select a point on the boundary line. Point A on the 1100-ft. contour was chosen. The difference in elevation between the 1100- and 1200-ft. contour is 100 feet. The radius of the cone 100 feet below the vertex is AB. (See front elevation.) With radius AB and center at A (see map), sweep the arc B. Interpolate between the contours and, in a similar manner, establish a series of such arcs. Draw curve C tangent to the arcs just established. Curve C is a contour of the dump at the 1200-ft. elevation. The area within curve C is level. Locate a ridge along which material can now be dumped so it will just roll down to curve C. Locate a point (point Q in this case) at some arbitrarily selected elevation (the 1300-ft. elevation was chosen). Point Q so chosen will be 100 feet above the datum plane. The radius of the cone 100 feet below the vertex is AB. Draw a curve parallel to the southwestern branch of C and a distance AB from C. Draw another curve parallel to the northeastern branch of C and a distance AB from C. Point R will lie at the intersection of the two curves drawn parallel to C. In a similar manner, establish other points, as P and R, and draw the outline of the ridge through them. The highest point from which material should be dumped, in this case, is at the 1332-ft. elevation.

11-XVII. Intersecting Cones by the Slicing Plane Method. To find the line of intersection between two cones when their axes intersect and their bases lie in non-parallel planes: Connect the vertices F and A and extend the straight line until it cuts the two bases at P and H. All slicing planes must contain line PH. Assume point B at some conveniently located position on the line of intersection between the two bases so that plane PHB will cut both bases of the cones. Elements F1 and F2 will be cut from the F cone, and elements A3 and A4 will be cut from the A cone. Four points on the

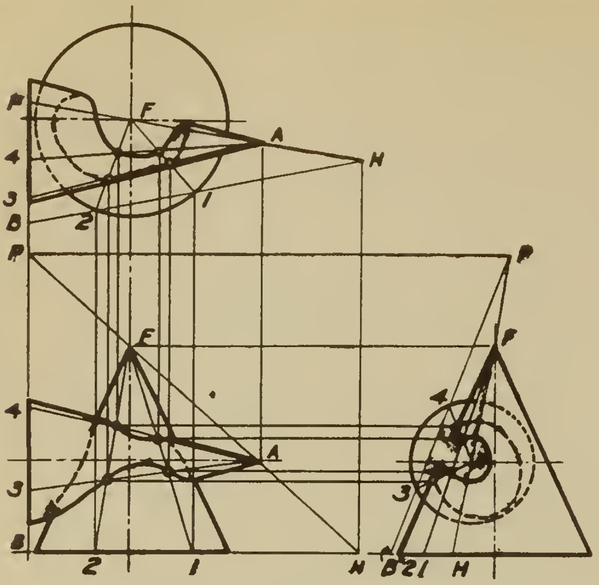


Figure 22-XVII. Intersecting Cones by the Slicing Plane Method

desired line of intersection will thus be located. The intersection of A3 and F2 will locate one point. The intersection of A3 and F1 will locate another point, etc. Additional planes can be used in a like manner to establish a sufficient number of points to determine the required line of intersection.

12-XVII. Intersection of Cones and of Cylinders by the Sphere Method. A sphere, with its center on the axis of a right, circular cone will cut two circles from the cone, if the proper diameter is chosen for the cone. When the axes of two right, circular cones intersect, the point of intersection can be taken as the center of the sphere. Each sphere will cut two circles from each of the two cones. Each circle of one cone will intersect none, one, or two of the circles of the other cone. The number of points on the line of intersection so determined by a single sphere will be zero, two, four, six, or eight. Views should be chosen which will represent the axes in true length.

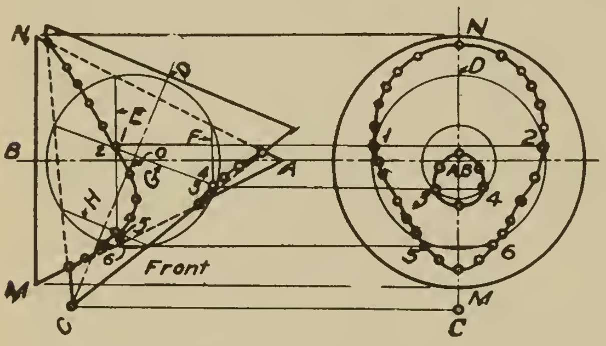


Figure 23-XVII. Sphere Method of Determining Intersection of Right Cones

Axes of the Cones, Figure 23-XVII, intersect at O in the front view which is the center of the cutting spheres. To locate the line of intersection: With center at O (front view) and a suitable radius, draw a sphere cutting circles F and E from the A cone and circles H and G from the C cone. Circles G and E intersect to locate points 1 and 2. Circles G and F intersect to locate points 3 and 4. Circles E and H intersect to locate points 5 and 6. Thus six points are located. Additional spheres can be drawn and a sufficient number of points located which will determine the desired line of intersection.

To Find the Line of Intersection between Two Right Circular Cylinders when their axes intersect and their bases lie in nonparallel planes, Figure 24-XVII: A cutting sphere with proper diameter will cut two circles from each cylinder. The circles so cut will intersect to locate none, two, four, or eight points on the line of intersection. The axes intersect at O in the view showing the axes in true length. Procedure: With center at O, draw a sphere R with suitable radius.

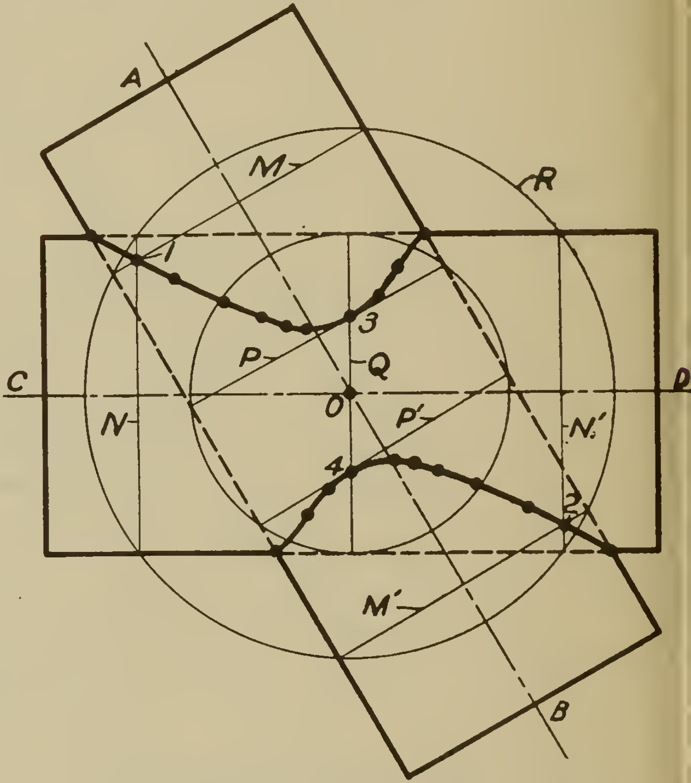


Figure 24-XVII. Sphere Method of Determining Intersection of Right Cylinders

Circles M and M' are cut from cylinder AB and the circles N and N' are cut from cylinder CD. Circles M and N intersect to locate points 1 and 1' (one point is behind the other) and circles N and N' intersect to locate points 2 and 2' (one point is behind the other). Thus four points are located. Draw additional spheres which will locate a sufficient number of points properly to locate the desired line of intersection.

To Find the Line of Intersection between a Right Circular Cone and a Right Circular Cylinder when their axes intersect and their bases lie in nonparallel planes, Figure 25-XVII. The axes intersect at O and are in true length. Procedure: Draw a sphere with radius R and center at O. Circles M and M' are cut from the cone, and the circle N is cut from the cylinder. Circles M and N intersect to locate points 1 and 1' (one point is behind the other), and circles M' and N intersect to locate points 2 and 2' (one point is behind the other). Draw additional spheres which will locate a sufficient number of points properly to locate the desired line of intersection.

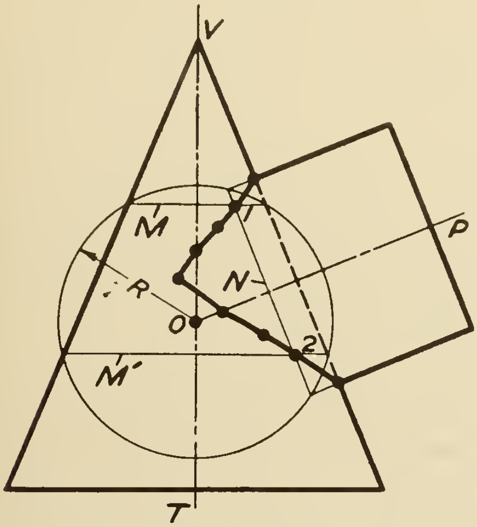


Figure 25-XVII. Sphere Method of Determining Intersection of Right Cone and Cylinder

13-XVII. Tangent Planes. Since two intersecting lines will determine a plane, a plane tangent to any surface at a point will be determined by any two lines drawn tangent to the surface through the point. In the case of a ruled surface, the plane is determined by a line drawn tangent to the surface through the point and any element of the surface which passes through the point. In the case of a double-curved surface, the tangent plane is determined by two different lines drawn tangent to two elements of the surface passing through the given point, when the elements intersect at the point.

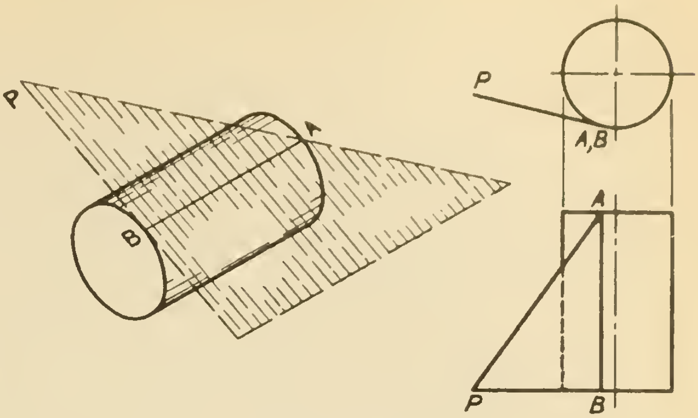


Figure 26-XVII. Plane Tangent to a Cylinder

To Construct a Plane Tangent to a Cylinder Containing a Point Not on the Cylinder: The plane will be determined by a line drawn through the point, Figure 26-XVII, tangent to the base (or tangent to the curve of a right section of the cylinder) and the element which passes through the point of tangency. The right section will have to be cut by a plane containing the point. Procedure: Since the given point P lies in a base of the cylinder, draw a line through P tangent to the circle of the base at B. Draw the element AB. Plane PAB is tangent to the cylinder along element AB. Two solutions are possible.

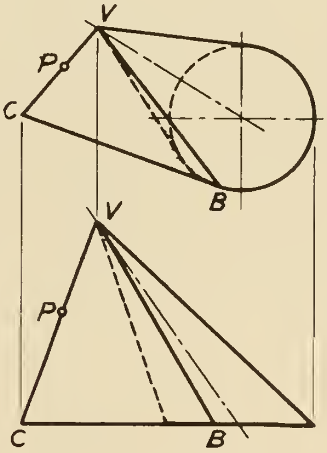


Figure 27-XVII. Plane Tangent to a Cone

To Construct a Plane Tangent to a Cone Containing a Point Not on the Cone: The cone is oblique, Figure 27-XVII, and the point P is not in the plane of the base. Procedure: Through the vertex V in the front view, draw VP extended until it cuts the plane of the base at C. Through C in the top view, draw a line tangent to the base at B. Draw the element VB. Plane PVB is tangent to the cone along element VB. Two solutions are possible. Alternate Procedure: Through P construct a plane perpendicular to the axis of the cone and cutting the cone. Point P now lies in the new base of the cone just formed. Follow the procedure given for constructing a plane tangent to a cylinder.

To Construct a Plane Tangent to a Sphere Containing a Line Not on the Sphere: Procedure: See Figure 28-XVII. Obtain an auxiliary view of the sphere showing line AB as a point. Through point AB in the auxiliary draw a tangent to the sphere at point C.

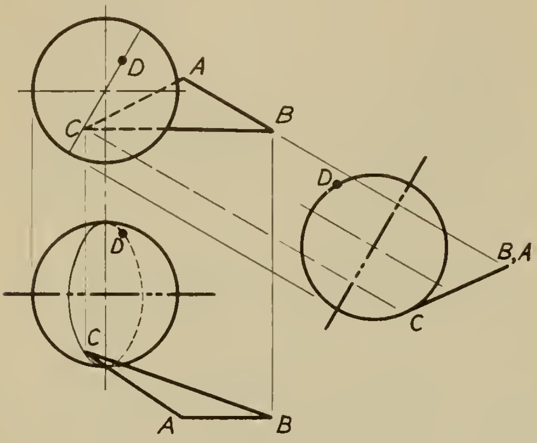


Figure 28-XVII. Plane Tangent to a Sphere

Point C lies on an element of the sphere (a great circle). Plane ABC is tangent to the sphere at point C. Two solutions are possible. If it were required to draw a plane tangent to the sphere at point D: Through D draw two great circles of the sphere (elements). Construct tangents to each element at D. The two tangents will intersect at D and locate a plane which is tangent to the sphere at D. Tangent plane construction is used in designing streamlined surfaces. See Articles 22-XII and 14-XVII.

14-XVII. Streamlining. The reader is referred to Article 22-XII for additional material on streamlining.

The pontoon covering of Figure 29-XVII is designed as a convolute surface in three sections. Surface Omn covers the upper half of the surface. It comes to a point at O, terminates in the frontal curve mnu and the horizontal curve vOe. Surface OLA forms the left half and surface OLB the right half of the lower part of the pontoon. Planes R and R' cut sections in the front view, as indicated. Ribs (supports) can now be placed in the position of the planes.

A plane tangent to the convolute will be tangent to the surface along an element. The plane will therefore be tangent to every curve of the surface at the point where the curve intersects the element.

22°

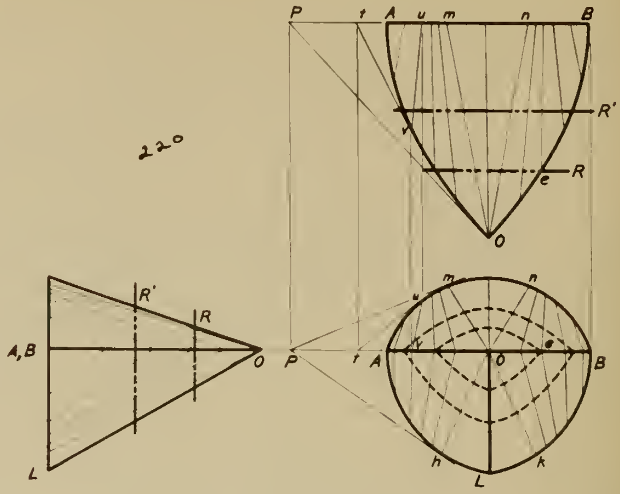


Figure 29-XVII. Pontoon

To locate elements in the convolute surface: Select any point u on the vertical curve mn. Tangent ut is a line of the plane which is tangent to the surface. Take t as a point in the plane which is tangent to the surface and tangent to curve AO. Draw tangent tv. Plane tvu is tangent to the surface, and uv is an element of the surface. Tangents Pm and PO form another plane, thus locating element mO. Line mO is a limiting element of the surface. Surface Omn is a segment of an oblique cone. Plane POn is tangent to the lower surface and Oh is a limiting element of the lower surface; similarly, surface Ohk is a segment of an oblique cone.

The surface can now be developed by extending consecutive elements until they meet and develop the greater surface by triangulation. Then lay off in each triangle the corresponding quadrilateral which will form the neat surface.

The Ship Surface of Figure 30-XVII is a double-curved surface. Three views, front (side elevation), plan (bottom view), and right side (end elevation) are shown. Elements of the surface are contours cut by horizontal planes a, b, c, etc., set at different elevations. The curves of the contours are seen in the bottom view. If vertical (bow) planes were passed through lines 1, 2, 3, etc., the bow curves seen in the end elevation would be cut from the ship. Thus the curves (elements) seen in the plan and end elevation truly delineate the surface of the ship. In ship construction, level and profile planes are set up as reference planes.

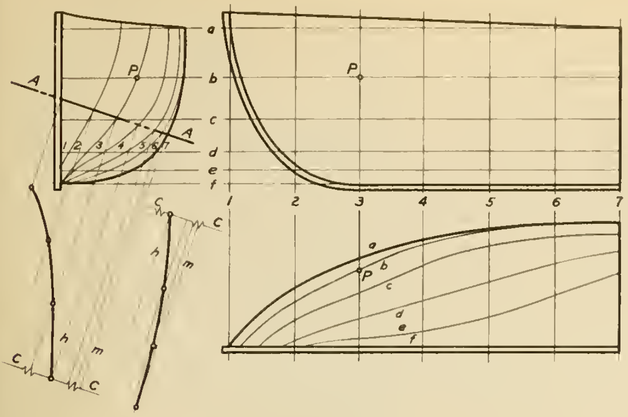


Figure 30-XVII. Ship

Coordinates are measured from each at corresponding elevations to locate ribs, surface plating, etc.

If the scale to which a ship drawing is made is 1/8" = 1'-0", the ship would be 96 times as large as the drawing. An error of a fourth-dimension on the scale (or one-half inch) would result in an error of 48" on the ship. As a check, curves of the plan and end elevation views are laid out on specially prepared flat surfaces of sufficient size to take the full-scale drawings.

It is usually desirable to determine whether or not the surface is "fair." Such a check is made by taking a section A-A as indicated. If the curve is smooth, the surface is fair. The surface of Figure 30-XVII is therefore thought to be satisfactory. It was necessary, in this case, to break the curve along line C-C in order to make the drawings compact.

15-XVII. Shop Terms and Practices. In order to execute a drawing intelligently, the draftsman must first know the purpose of the drawing and the uses to which it is to be put. That is, if he is to prepare a drawing of an object that is to be made in the shop, he should know shop terms and practices. The structural draftsman should know construction methods. The map maker not only should know surveying and field methods, but should also know the uses to which his maps will be put. In brief, the draftsman should know the methods and practices of the craftsman or person who is to use his drawing in order to supply the necessary information. This information should be placed on the drawing where the user would expect to find it.

The best way to gain this information is through experience, which is not, however, always possible. Nevertheless, a great deal can be learned through observation while visiting shops and engineering works and from the experiences of others. Also, one should read regularly the current periodicals of his branch of engineering.

The object of this section is to acquaint the beginner with some of the terms of the shops and the practices followed there, since a large part of his work will have to do with drawings of objects to be made in one or more of the common shops which are: (1) pattern shop, (2) foundry, (3) forge shop, (4) machine shop, and (5) assembly shop.

Pattern Shop. Detail drawings for all castings are first sent to the pattern maker who makes a copy of the object in either wood, plaster, or "white metal." The model is called a pattern, Figure 31-XVII on the following page.

The dimensions on the drawings are the dimensions for the finished object. Since a casting will shrink as it cools, the pattern must be made oversize. This oversize allowance is called the pattern-maker's rule. Also, if a casting is to be machined or finished, extra metal must be allowed for this operation. These allowances are taken care of by the pattern maker, usually allowing about one-eighth of an inch to a twelve-inch measurement. The allowance for machining depends upon the size and shape of the casting. The allowance will vary from one-eighth to three-quarters of an inch per casting, depending upon the size of the object.

The pattern maker studies the drawing to see how the pattern--and then the mold--can best be constructed. The mold may be made "solid", "two-part", or "three-part", etc. The pattern is made with a slight taper so it can be easily withdrawn from the mold. This taper is called the draft or draw of the pattern. In dividing the mold into two or more parts, at least one plane of cleavage or parting plane will be necessary. The line on the drawing denoting a division in the mold is called the parting line. Neither the plane nor the line is put on the drawing.

Sharp angles in a casting cause checking and are therefore places of weakness. To overcome this, excess metal is added by placing quarter-rounds of wood, leather, or wax in these angles of the pattern. The additional metal thus placed provides fillets. The outside edges of the casting are rounded off by placing sand, with a small, sharp pointed trowel, in the corresponding corners of the sand mold.

Small holes in a casting are usually drilled. The larger holes or cavities more often are formed by placing a core in the

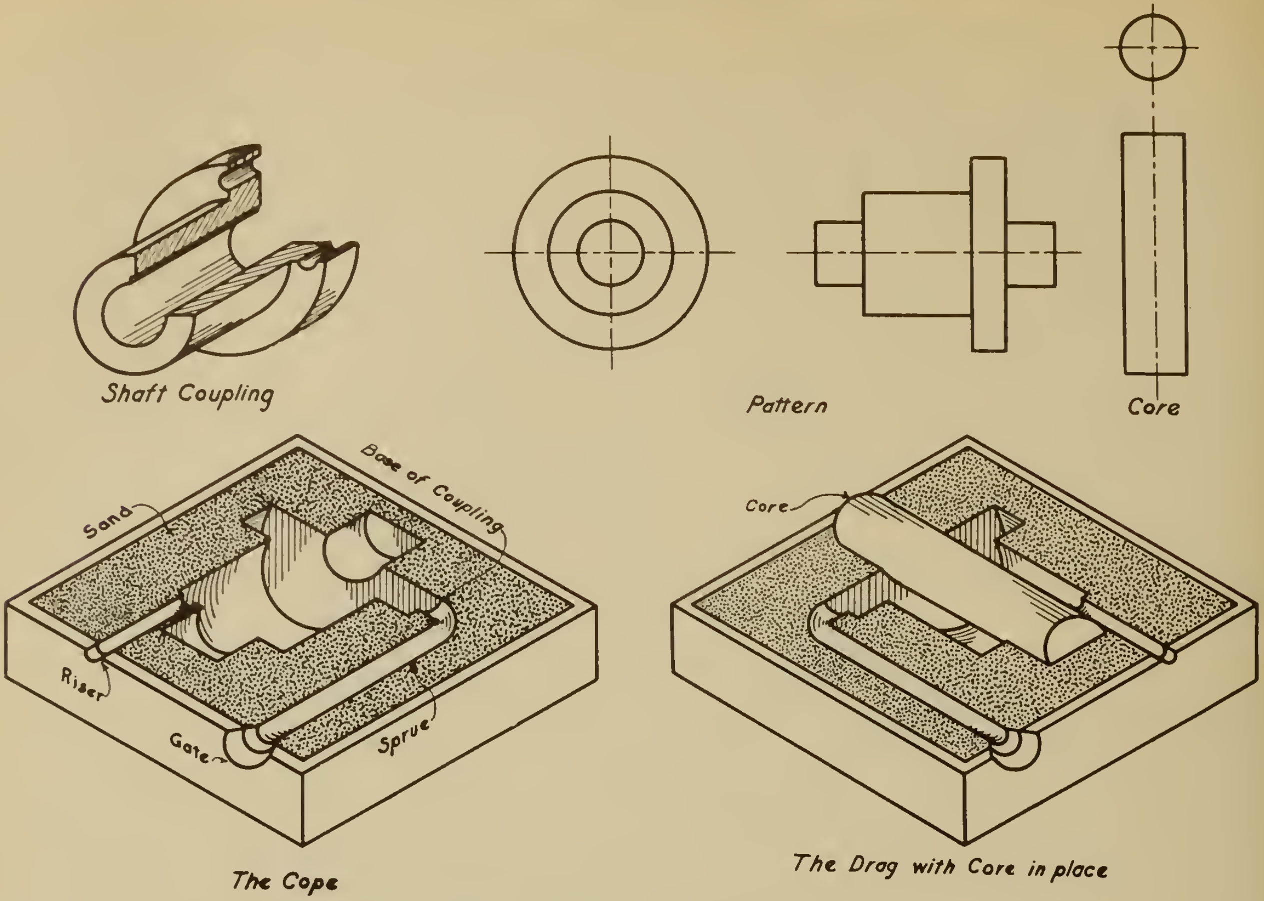


Figure 31-XVII. Pattern Molding

mold when the casting is poured, Figure 31-XVII. They are made of a mixture of specially prepared sand and binding material and are then baked hard in a core oven. Cores are formed in a wooden box called a core box. The box is constructed by the pattern maker while the core is made at the foundry. The projections or dowels on the core which hold the core in place in the mold are called core prints.

Foundry. The pattern and cores are sent to the foundry and the castings made. Only occasionally does the foundry force need the draftsman's drawings or his assistance. However, the draftsman should know the operations performed there and the methods employed by the foundrymen. The principal equipment consists of a cupola, Figure 32-XVII, in which the metal is melted before the casting can be poured, the sand from which the molds are made, and the oven in which the cores--and sometimes the molds--are baked.

The mold is made in two or more parts (see "Pattern Shop"). The bottom part is known as the drag, the top part, the cope, and the intermediate part or parts, the check or checks. The various parts which make up the mold are called the flask. Metal is poured into the mold through the gate and is led to the bottom of the cavity through a sprue. The cavity is ventilated at the top by a riser, Figure 31-XVII.

Forge Shop. Many machine parts are either forged, rolled, or pressed into shape rather than cast. Also the heat treatment of metal--a special treatment--is usually done in the forge shop.

Forging is done by hand--hand forging--or by trip hammers--drop forging. The metal may be hammered into a die, it may be rolled or pressed into shape, or there may be a combination of these operations in manufacturing the object.

Steel that is to be used for cutting must first be tempered by heating the soft steel, after it has been worked into shape, to a temperature near cherry red--about 1600 degrees Fahrenheit--dipping, allowing to cool to about 500 degrees, then plunging (quenching) into a bath of water or oil. The temper can be drawn by heating the piece and then allowing the part to cool without quenching.

With repeated heatings, the steel becomes harder and more brittle. If a softer

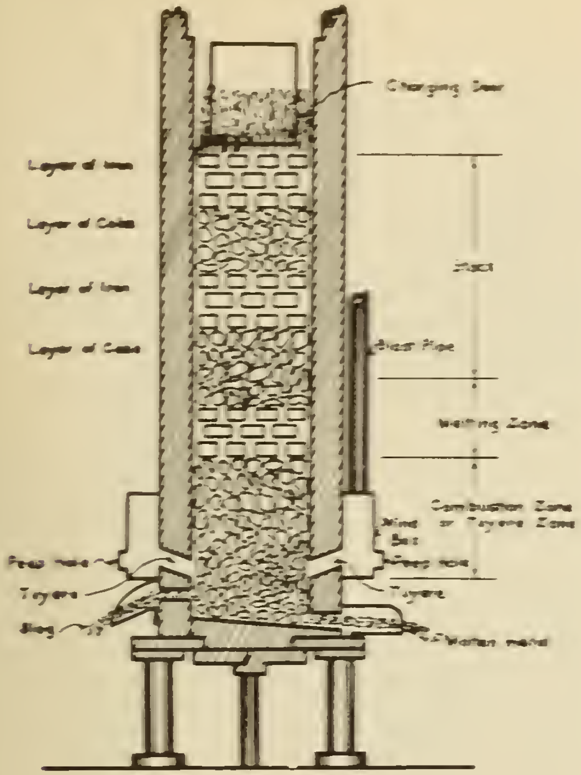


Figure 32-XVII. The Cupola

steel is desired, the part is annealed, by placing the object in a receptacle or bath and then heating to a red heat. The object is then cooled by a like process.

Arc Welding. A new process of manufacturing machine parts, also used for fastening, is known as arc welding. It is gaining rapid acceptance and is fast cutting into the operations of the foundry and forge shops. It is used extensively in making joints. The process consists of building up structural parts, i.e., machine bases, columns, beams, pedestals, and the like, from plates and standard steel shapes by joining them through the process of electric arc welding. Figure 40-XVII. By this process it is possible to secure greater strength and rigidity with less weight of metal, since steel is six times as strong in tension as cast iron and two times as stiff.

It is possible to make an arc welded joint as strong as the part itself, which makes it much more efficient than the riveted joint.

Welded joints are either continuous weld or tack weld. Figure 33-XVII. Continuous welds are not, as a rule, detailed but are indicated by a note describing the size of the welded bead--1/4" bead, 3/8" bead, etc. Intermittent welds are usually designated as tack welds--2" long, 6" long, etc.

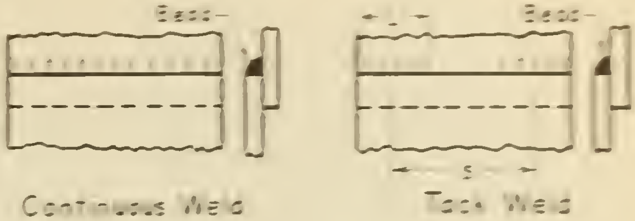
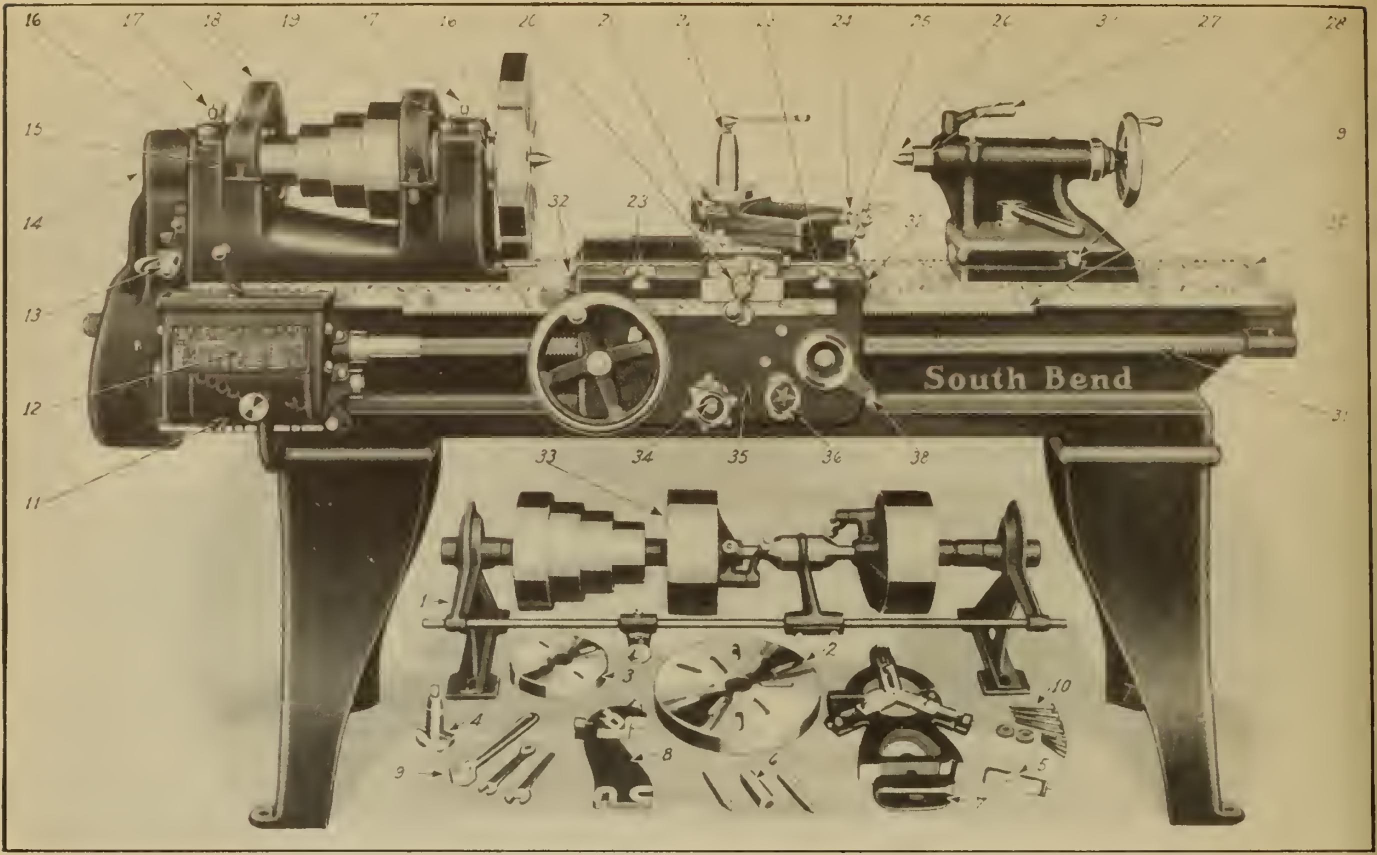


Figure 33-XVII. Arc Welding

Machine Shop. Articles manufactured in the above-mentioned shops are taken to the machine shop to be finished according to the drawings or specifications. Some articles are made (turned down) in the machine shop. The more common machines in use are the lathe, boring machine, drilling machine, milling machine, planer, shaper, grinding machine, and broaching machine. They will be described more in detail in the following paragraphs.

Practically all turning, i.e., machining of cylindrical surfaces such as glands, spindles, and thread cutting, is done on the lathe. Figure 34-XVII. It is the most generally used piece of machinery in the machine shop. The part to be turned down (the work) is held between the headstock and the tailstock and is revolved at high speed by power applied through the headstock. A tool post holds the cutting tool which can be moved parallel to the axis of the part to be machined. At each operation the tool cuts off a thin layer of the metal. Repeated cuttings

Figure 35-XVII. Some Small Tools
Courtesy Cleveland Twist Drill Company



1. Double friction countershaft
2 and 3. Face plates
4. Tool post, ring, and wedge
5. Thread cutting stop
6. Headstock spindle sleeve with centers
7. Steady rest
8. Follower rest
9. Set of wrenches for tailstock, compound rest and tool post
10. Lag screws and washers for securely fastening lathe to foundation
11. Quick change gear box
12. Index plate for threads and feeds
13. Quick-acting latch reverse
20. Micrometer collar on cross feed screw
21. Compound rest graduated 180 degrees
22. Forged steel adjustable tool post
23. "T" slot for clamping work on carriage
24. Micrometer collar on compound rest screw
25. Carriage lock for facing
26. Tool steel lathe centers
27. Tailstock spindle lock
28. Set-over tailstock for taper turning
29. Steel rack, cut from the solid
30. Semisteel seasoned lathe bed
31. Precision lead screw, Acme thread
33. Double friction countershaft
34. Automatic friction feed clutch
36. Knob for automatic feed
37. Graduated tailstock spindle
38. Half-nut lever for thread cutting

Figure 34-XVII. The Lathe

are made until the part takes the desired shape. Boring, reaming, threading, grinding, knurling, and polishing can be done on the lathe. However, special machines are provided for most of these operations when mass production is desired.

In Figure 35-XVII are illustrated some of the more common small tools used in the above operations. They are A, combination drill and countersinking tool; B, high speed drill (straight shank); C, high speed end mill (tapered shank with tang); D, hand reamer (some reamers are tapered); E, counter boring tool (with interchangeable pilot in front); F, wood bit (with pointed end for brace); G, high speed drill with oil tube (has tapered shank and tang); H, taper fitted socket for use with all taper shank tools. The tang of the socket fits in the machine and takes the tool in the open end. The tool is released from the socket by inserting a drift or counter key in the slot, thereby freeing the tool.

Cylindrical holes of considerable size or length are bored on the *boring machine* (or on the lathe), Figure 36-XVII. Engine cylinders, gun barrels, etc., are bored. The finished surface is much smoother and has a higher degree of tolerance than drilled holes. Small holes can be bored and all holes beyond the size and length of drills must be bored. The boring tool is held in place by a pilot as it advances into the piece. The pilot follows the tool in this case. See Figure 35-XVII.

Cylindrical holes, not bored or formed by cores when the casting is made, are to be drilled. Figure 37-XVII, is an illustration of a *drilling machine*. A drill bit Figure 35-XVII, is held in the drill spindle or socket through which power is applied. The spindle is given a vertical motion, either automatically or by hand, when advancing the bit into the metal or when withdrawing it, while the piece to be drilled rests on the bed of the machine. Most cylindrical holes are drilled. A hole must first be drilled before it can be tapped. The drilling machine can also be used for counterboring or for countersinking, a process which enlarges one end of a hole to take screw heads or small bolt heads.

Slots, keyways, gear teeth, and the like are usually cut on the milling machine, Figure 38-XVII. Bearings, the ends of bosses, and similar parts, are finished on a special *milling machine* called the *end mill*. The operation of a milling machine is similar in principle to the rotary saw. Circular discs with teeth, revolving at high speed, cut away the metal as the piece is fed under the cutter.

The *planer* is used to finish the surface of large flat pieces, Figure 39-XVII. The part is placed on a horizontal bed which moves with the piece back and forth under the cutting tool. At each run of the bed, the tool has a slight motion at right angles to the bed.

The *shaper* is a general utility finishing machine, and its functions are similar to those of the planer. It is also used for the cutting of grooves and slots. Its operations are the reverse of the planer. The tool is the fast moving part, and the bed is manipulated by the operator. Figure 39-XVII is a combination planer and shaper.

The *grinding machine*, Figure 40-XVII is used to take off the small amount of stock left after the last machine operation and to produce the final finish. (This operation should not be confused with polishing.) It includes emery wheels and high speed carborundums. External and internal grinding machines are available. The operation is performed on both stationary and revolving objects.

A surface is *polished* (not to be confused with ground) by the use of high speed discs of material such as leather, muslin, or composition. This operation gives a surface a luster impossible to obtain with a grinder.

The function of the *jig* and the *fixture* is often identical. They are used in machining articles where identical operations are to be repeated in exactly the same way. The operation of each differs, however. In general, the fixture is fastened rigidly to the machine and serves to hold the work in place while the tool is cutting. It is therefore called a fixture. The jig, on the other hand, may hold the work or it may be used as a guide or pattern for the cutting tool while holding the work. Figure 41-XVII illustrates a fixture in a milling machine. In Figure 42-XVII is shown a built-up (welded) jig used for drilling. The work fits inside.

A *broach* is a tool for cutting square or rectangular holes, internal slots, etc. It is a hard steel shaft of the required shape with cutting teeth along the sides. It is either pushed or pulled through a cylindrical hole to cut the required shape. A push broach is operated in a press. A broaching machine is illustrated in Figure 43-XVII.

*Tool Designing Department*. Many of the larger concerns maintain their own tool designing departments where they design and manufacture small tools needed in the various shops--especially the machine shop--such as jigs, fixtures, and machine tools for the manufacture of the finished parts. This department is a very important cog in the economic structure of an industrial organization.

*Assembly Shop*. After the various parts have been manufactured or fabricated the machine or structure is assembled in part or entirely in the assembly shop. Assembly drawings which show the exact location in the structure of each piece or each section are used for this work. Larger units such as excavators, conveyors, elevators, transmission machinery, and the like are shipped to the job assembled in sections, and are there erected. Erection drawings showing the exact location in the structure of each section are used by the erection crew in assembling the various sections.

*Machine Drawing*. A machine drawing is illustrated in Figure 44-XVII. The

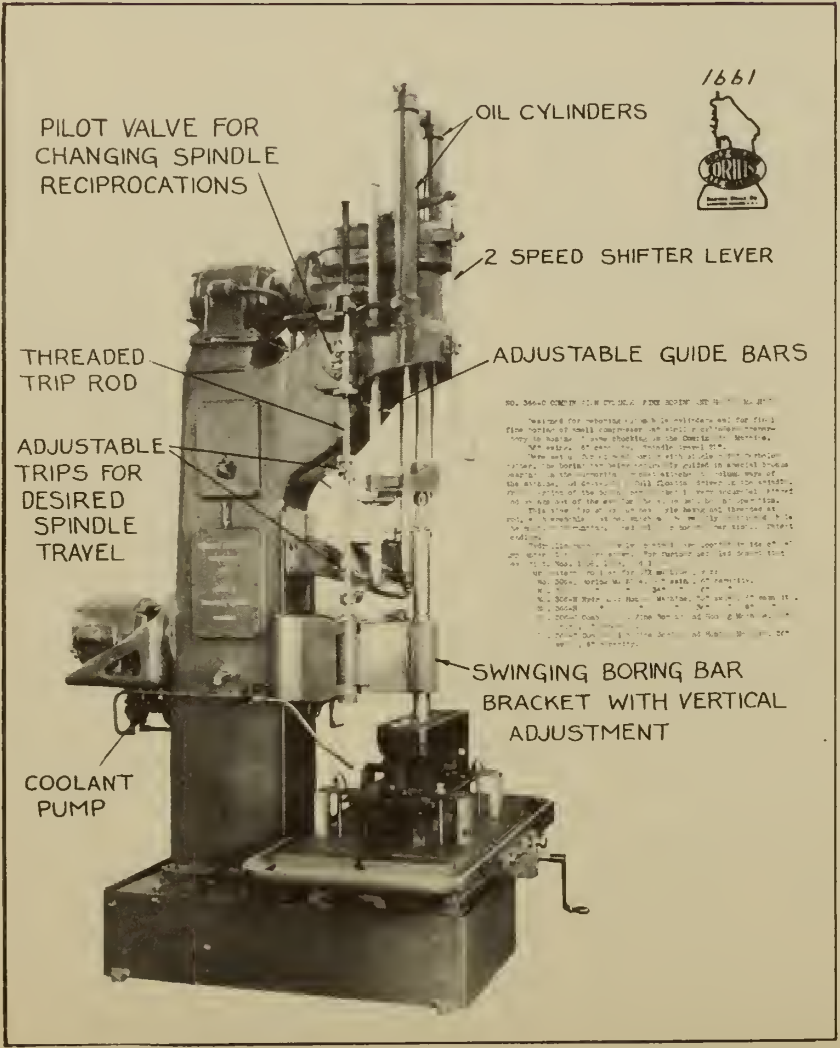

1661
PILOT VALVE FOR CHANGING SPINDLE RECIPROCATIONS
OIL CYLINDERS
2 SPEED SHIFTER LEVER
THREADED TRIP ROD
ADJUSTABLE GUIDE BARS
ADJUSTABLE TRIPS FOR DESIRED SPINDLE TRAVEL
SWINGING BORING BAR BRACKET WITH VERTICAL ADJUSTMENT
COOLANT PUMP

Figure 36-XVII. Boring and Honing Machine

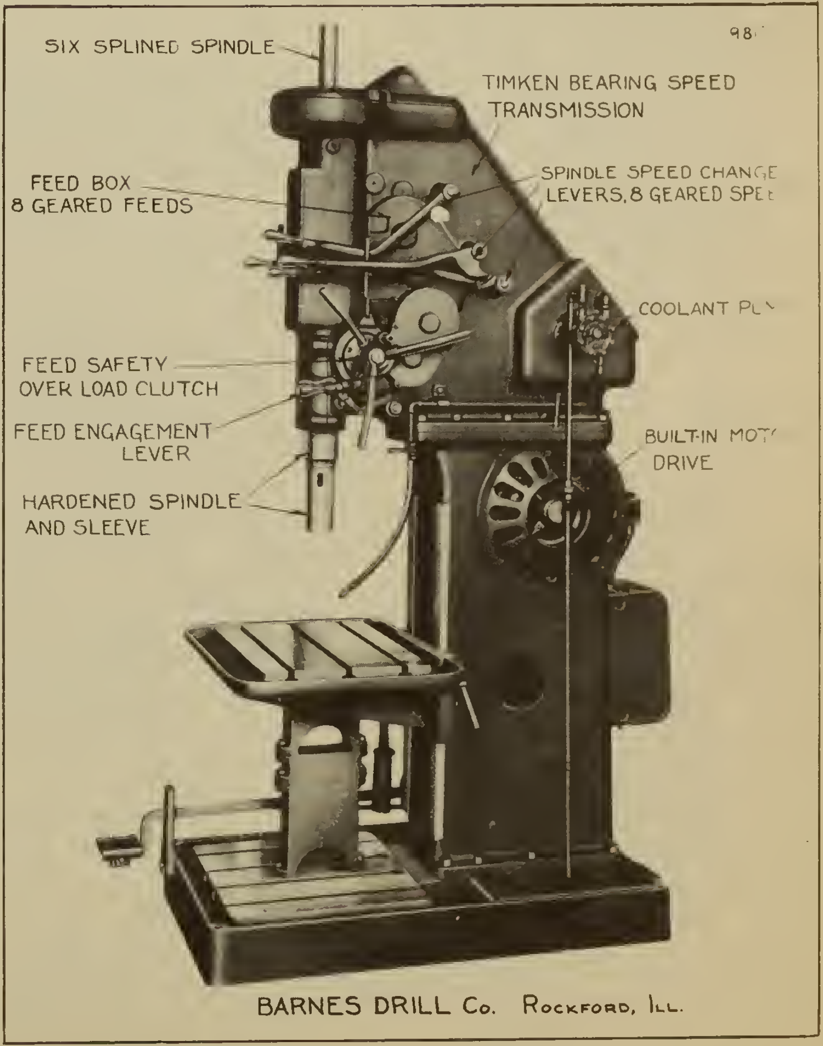

SIX SPLINED SPINDLE
98
TIMKEN BEARING SPEED TRANSMISSION
FEED BOX 8 GEARED FEEDS
SPINDLE SPEED CHANGE LEVERS, 8 GEARED SPE
COOLANT PU
FEED SAFETY OVER LOAD CLUTCH
FEED ENGAGEMENT LEVER
BUILT-IN MOT DRIVE
HARDENED SPINDLE AND SLEEVE
BARNES DRILL Co. Rockford, Ill.

Figure 37-XVII. Drilling Machine

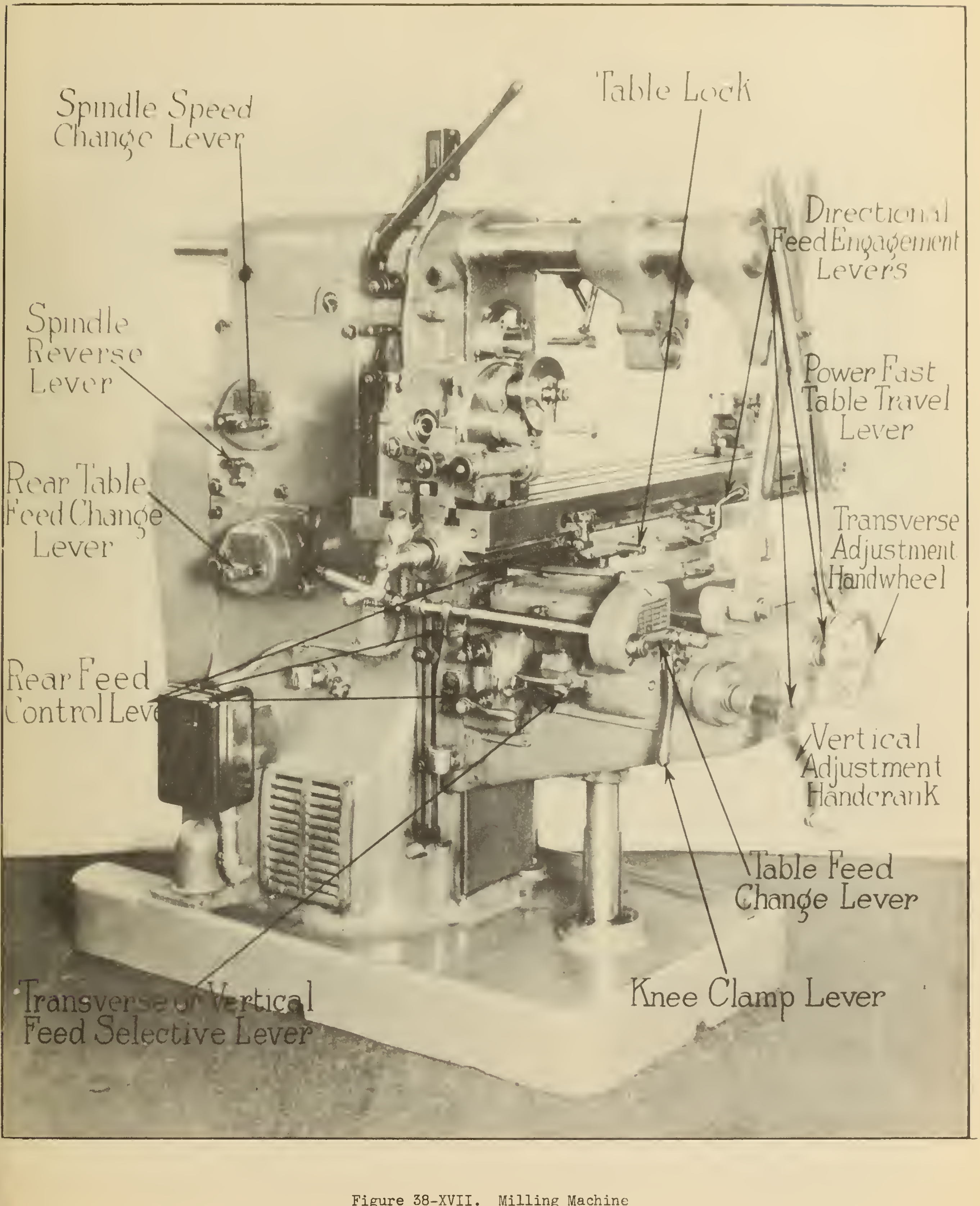

Spindle Speed Change Lever
Table Lock
Directional Feed Engagement Levers
Spindle Reverse Lever
Power Fast Table Travel Lever
Rear Table Feed Change Lever
Transverse Adjustment Handwheel
Rear Feed Control Lever
Vertical Adjustment Handcrank
Table Feed Change Lever
Knee Clamp Lever
Transverse or Vertical Feed Selective Lever

Figure 38-XVII. Milling Machine

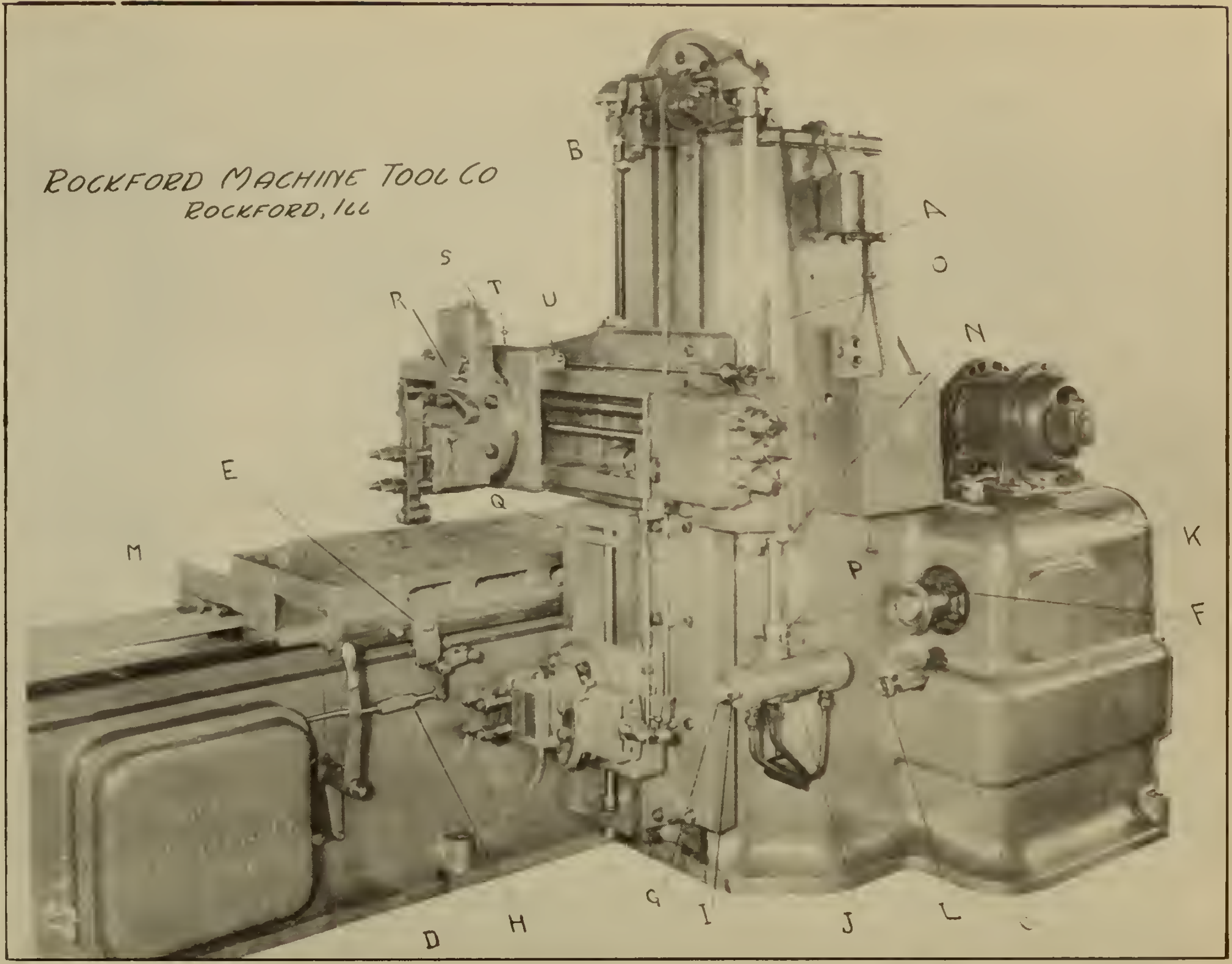


Figure 39-XVII. Hydraulic Planer and Shaper

A--Electric Reverse drum, controlling direction of head rapid traverse and rail elevation.
B--Rail elevation control, engages elevation after direction has been selected through A.
C--Table speed control on cutting stroke. Continuity of changes between minimum and maximum.
D--Table stop and start lever.
H--Table reverse control. Table may be reversed at any point, either forward or reverse through this control.
I--Adjustment of feeds to heads. Continuity of changes between minimum and maximum.
L--Table speed control on reverse stroke. Continuity of changes between minimum and maximum.
N--Control for engaging feeds and automatic stops.

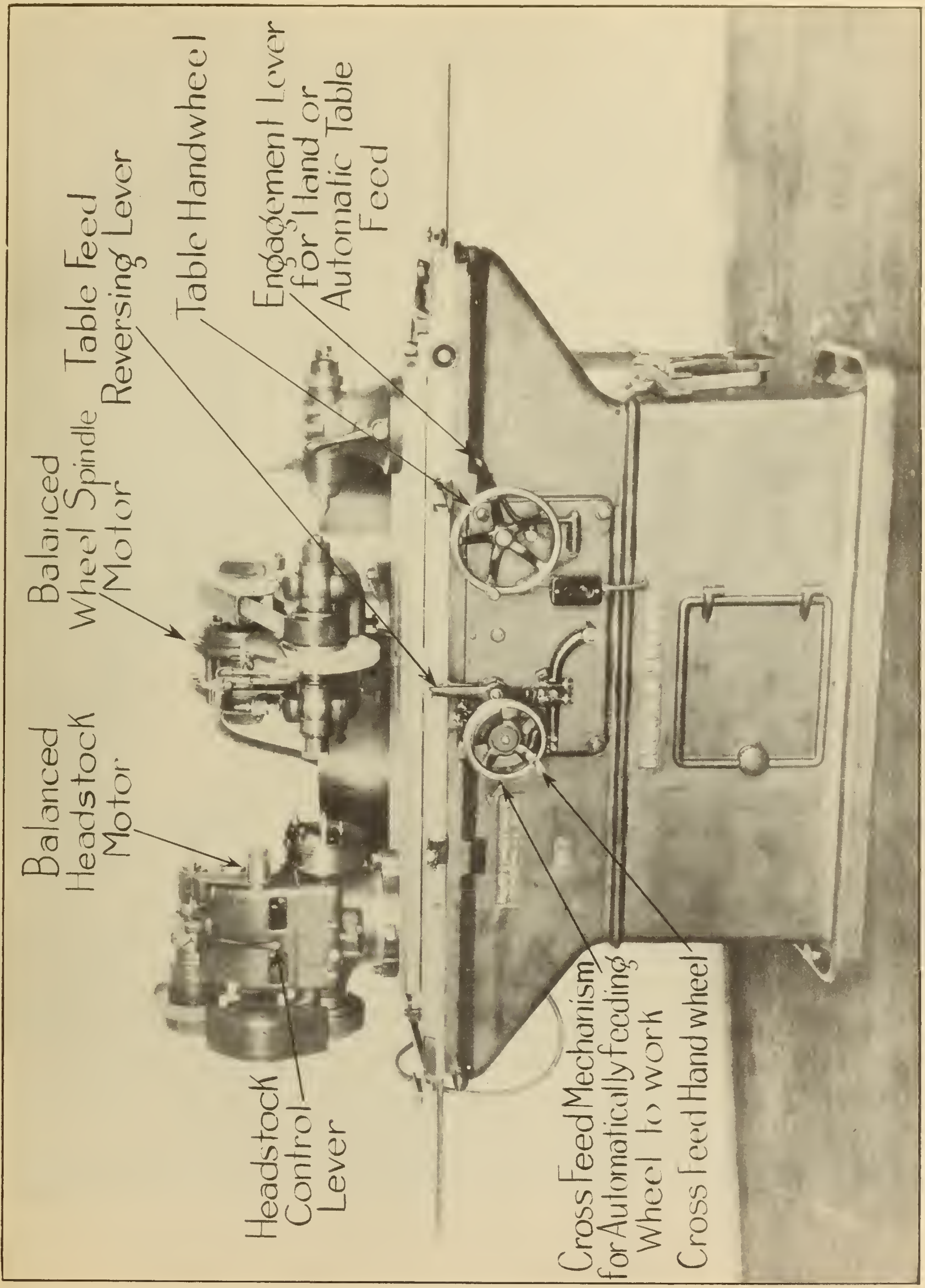

Balanced Headstock Motor
Headstock Control Lever
Balanced Wheel Spindle Motor
Table Feed Reversing Lever
Table Handwheel
Engagement Lever for Hand or Automatic Table Feed
Cross Feed Mechanism for Automatically feeding Wheel to work
Cross Feed Hand wheel

Figure 40-XVII. Grinding Machine

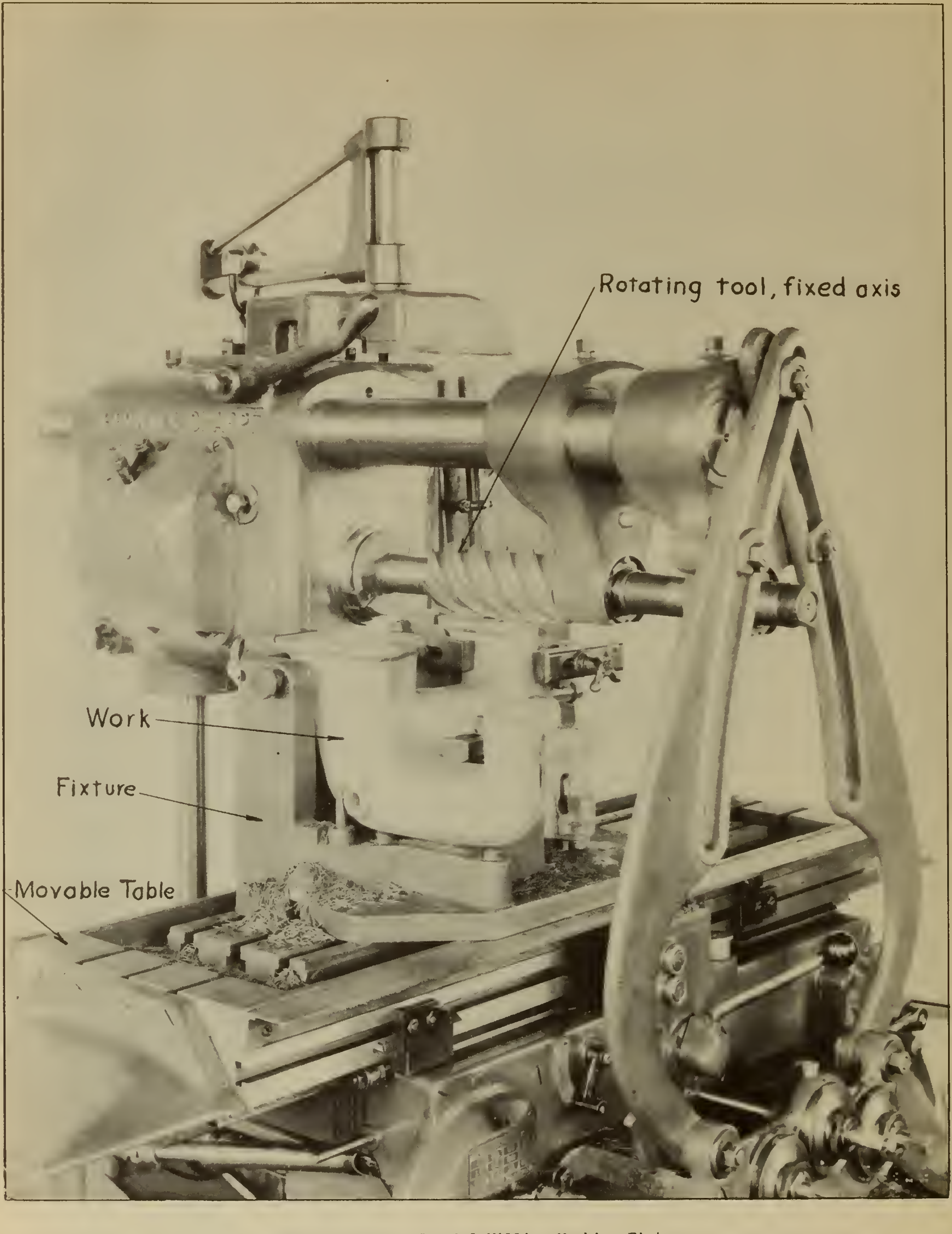


Figure 41-XVII. Special Milling Machine Fixture
Courtesy Brown & Sharpe Mfg. Co., Providence, R. I.

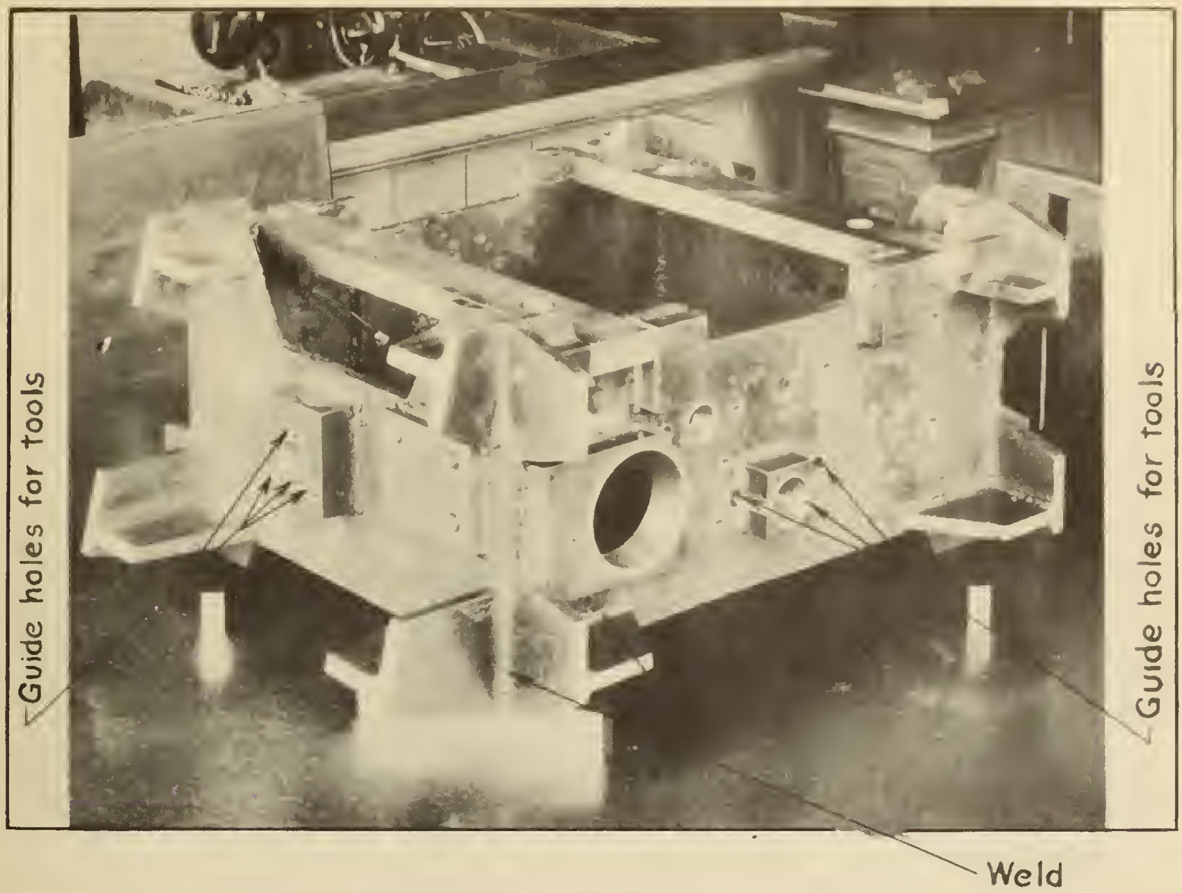


Figure 42-XVII. A Jig for Drilling
Courtesy Brown & Sharpe Mfg. Co., Providence, R.I.

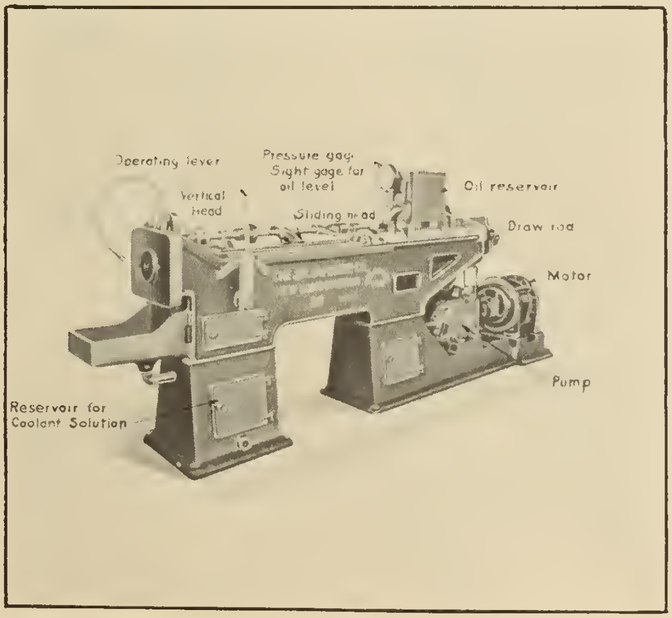
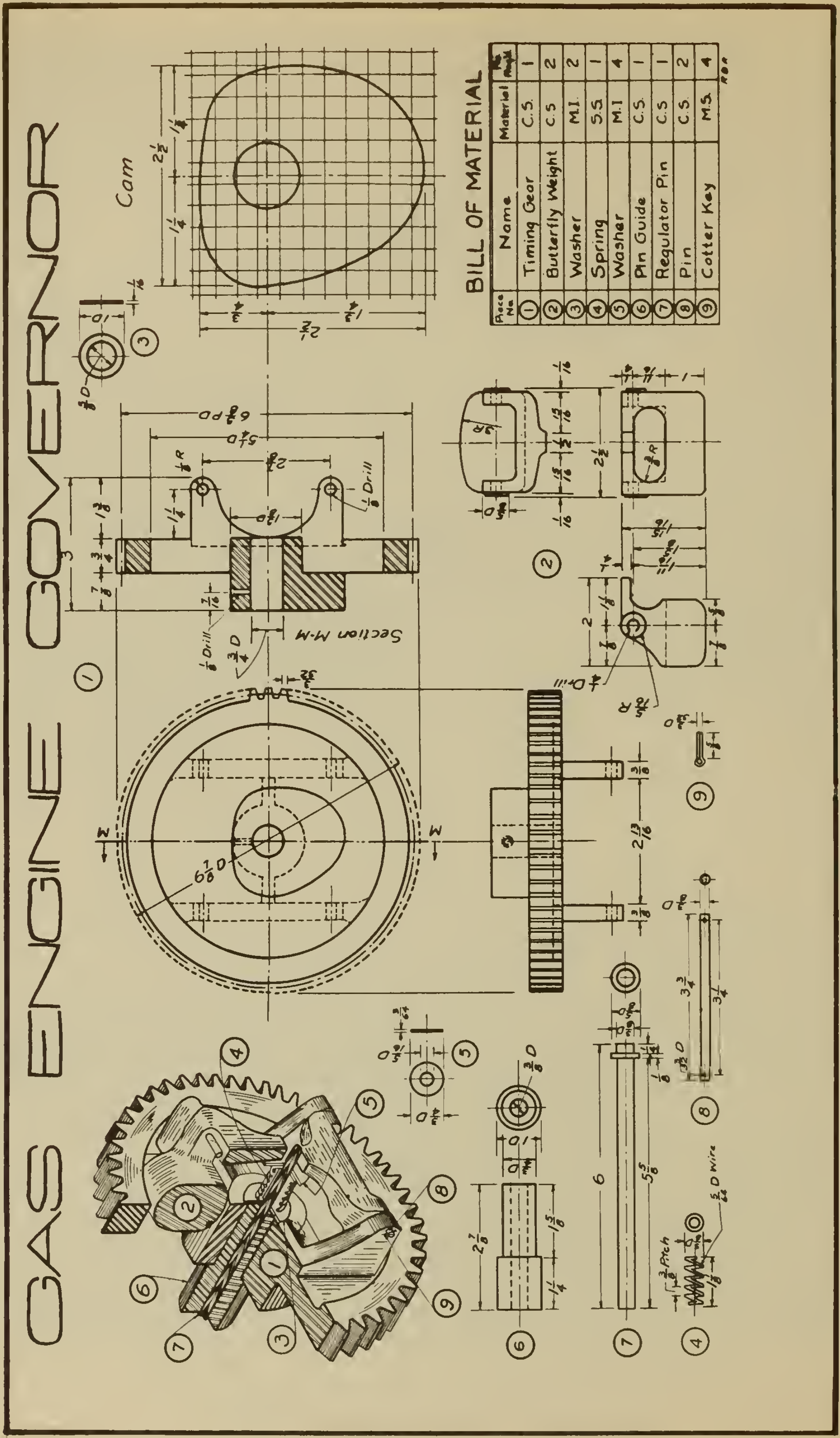


Figure 43-XVII. Hydraulic Broaching Machine



## BILL OF MATERIAL

| Piece No. | Name | Material | No. Req'd |
|---|---|---|---|
| ① | Timing Gear | C.S. | 1 |
| ② | Butterfly Weight | C.S | 2 |
| ③ | Washer | M.I. | 2 |
| ④ | Spring | S.S | 1 |
| ⑤ | Washer | M.I | 4 |
| ⑥ | Pin Guide | C.S. | 1 |
| ⑦ | Regulator Pin | C.S | 1 |
| ⑧ | Pin | C.S. | 2 |
| ⑨ | Cotter Key | M.S. | 4 |

RDR

Figure 44-XVII. Gas Engine Governor Assembly

assembly drawing might be in either pictorial or in orthographic. It will not be necessary in many cases to make an assembly. Other illustrations of a complete set of machine drawings may be found in Figures 20-XIV, 27-XV, and 28-XV.

## EXERCISES

16-XVII. The student will select the scale and problem space for each exercise. He should dimension and ink all drawings.

### Group 1-XVII. Intersection of Planes

1-6. Do exercises 1-6, Gr. 18, Ch. XI, by the "second method."

### Group 2-XVII. Line Making Specified Angles with a Horizontal and a Frontal Plane

1. Locate a line, AB, which is 4" long and makes an angle of 15° with a horizontal plane and 30° with a frontal plane. Point B is to the right of and below A.
2. Same as exercise 1 above, but draw AB in all possible positions.
3. Same as exercise 1, above but AB makes an angle of 33° with a horizontal plane and 23° with a frontal plane. Point B is to the left and above A.

### Group 3-XVII. Angle between a Line and an Oblique Plane

1-6. Do exercises 1-6, Gr. 20-XI, except use the direct method.

### Group 4-XVII. Plane Making Specified Angles with a Horizontal and a Frontal Plane

1. Locate point A just to the left of the center of the problem space. Draw plane ABC which makes an angle of 60° with a horizontal plane and 30° with a frontal plane. Locate point X just to the right of the center of the problem space. Draw plane XYZ which makes an angle of 28° with a horizontal plane and 65° with a frontal plane. Draw both planes in all possible positions.
2. Determine a plane ABC which makes an angle of 70° with a frontal plane and 58° with a horizontal plane. The points B and C are to the right of A, B is above A, and C is in front of A.
3. In the left portion of the problem space locate the plane MNO, which has a dip of 30° eastward and makes an angle of 60° with all frontal planes. In the right portion of the problem space draw plane PQR, which has a dip of 60° westward and makes an angle of 30° with a frontal plane. Find the line of intersection between the two planes.

### Group 5-XVII. Angle Between Two Oblique Planes

1-7. Do exercises 1-7, Gr. 21-XI except use the indirect method.

### Group 6-XVII. Framing a Hip and Jack Rafter

1. Roof layout: Scale 1/4" = 1'-0". Detail layout: Scale 3" = 1'-0". Use a double space. Pitch = 3/8. Run = 12'. (1) Show the face, edge, end view, and true length of a 2" x 6" common rafter. (2) Indicate the angles of cut.
2. Substitute "jack rafter" for the common rafter of exercise 1, above.
3. Substitute "hip rafter" for the common rafter of exercise 1, above.
4. Same as exercise 3, above, except use a 4" x 8" hip rafter. Run = 15'. Pitch = 1/3.
5. Truss layout: Scale 1/4" = 1'-0". Detail layout: Scale 3" = 1'-0". Use a double space. a 4" x 8" timber fits in a skew roof truss. The 8" face is vertical. The two ends of the beam are cut by a vertical plane which makes an angle of 30° with a frontal plane (or 60° with a profile plane) and slopes back and to the left in the plan view. Points A and B are the centers of the two ends. Point B is 22'-6" to the right, 15'-0" above, and 12'-6" north of point A. (1) Show the face, edge, end view, and true length of the timber. (2) Indicate the angles of cut.
6. Truss layout: Scale 1/4" = 1'-0". Detail layout: 3" = 1'-0". Use a double space. (1) Reproduce the drawing of Figure 18-VIII, a shed truss, and add a plan view. (2) Make dimensional drawings of each timber of the truss. (3) A total of six trusses will be used in the structure. How many "board-feet" will be needed? The draftsman should supply the missing dimensions for the various details.

7. Same as exercise 6, above, except the truss makes an angle of 30° with a frontal plane and extends back and to the right.

## Group 7-XVII. Architectural Drawing

1. Dimensions for overnight shelter, Figure 11-XVII (page 211): Size 12'-0" x 12'-0" over-all. Ridge pole 9'-0" high and 4'-0" from front. Front eave 6'-6" high. Rear eave 4'-0" high. Draftsman should supply any missing details or dimensions. Make the following dimensional drawings: (1) Plan. (2) Front elevation. (3) End elevation. (4) What is the pitch of each roof? (5) Give a bill of material. Lodge poles are used and will average 8" in diameter. (6) Reproduce the pictorial sketch of the shelter.
2. Copy the plan of Figure 45-XVII and draw (1) a front elevation, (2) end elevation, and (3) make a free-hand pictorial sketch of the log cabin. The side walls are 7'-7" above the floor. Roof pitch = 1/3. (4) Give a bill of material (see Figure 11-XVII). The draftsman is to furnish missing details and dimensions. The plan, front, and end elevations are to be dimensioned. Lodge poles are to be used and will average 8" in diameter.

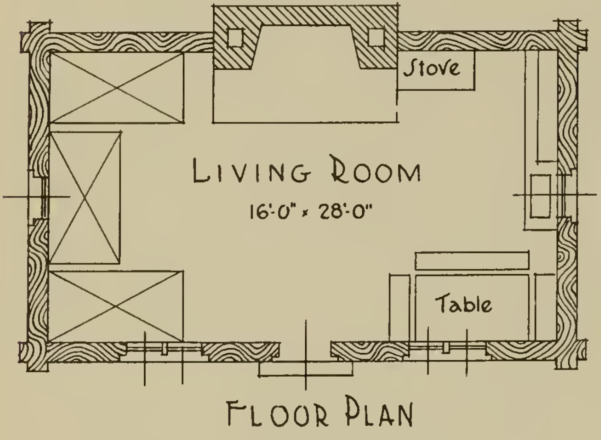


Figure 45-XVII. One-room Log Cabin

3. Copy the plan of Figure 46-XVII and draw (1) a front elevation, (2) end elevation, and (3) make a free-hand pictorial sketch of the log cabin. The side walls are 12'-6" above the floor. The ceiling is 8'-0" above the floor. Pitch of roof = 5/12. (4) Give a bill of material (see Figure 11-XVII). The draftsman is to furnish missing details and dimensions. The plan, front, and side elevations are to be dimensioned. Lodge poles are to be used and will average 8" in diameter.

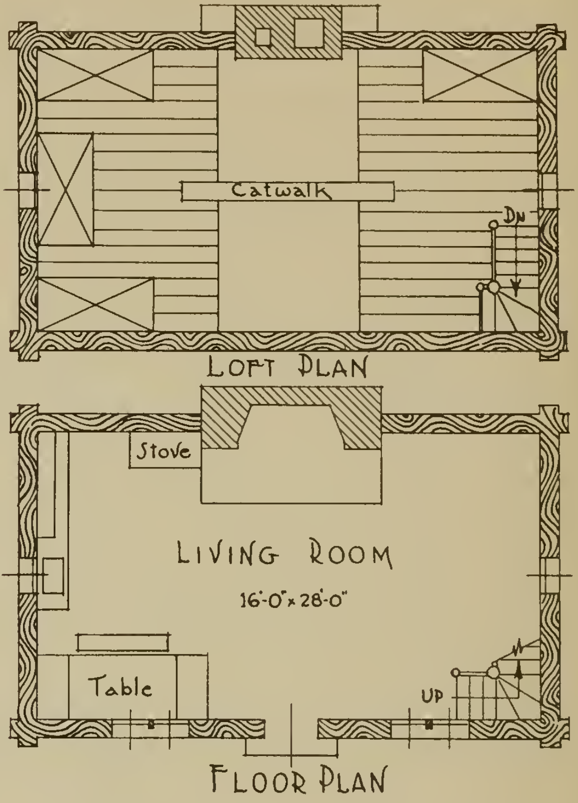


Figure 46-XVII. One-room Log Cabin with Attic Development

4. Copy the plan of Figure 47-XVII. Other data as given in exercise 2, above.
5. Copy the plan of Figure 48-XVII. Other data as given in exercise 2, above.
6. Copy the plan of Figure 49-XVII. Pitch = 5/12. Other data as given in exercise 2, above.

## Group 8-XVII. Vectors

In each of the following exercises give in pounds the value of the resultant of the given systems of forces. Indicate the direction of the resultant. Force scale 1" = 100 lb. Indicate compressive or tensile stresses by C or P respectively.

1. Scale 1" = 1". Figure 50-XVII (A).
2. Scale 1" = 1". Figure 50-XVII (B).
3. Scale 1" = 1". Figure 50-XVII (C).
4. Scale 1" = 1". Figure 50-XVII (D).
5. Scale 1" = 1/4 mi. Use suitable scale for vector diagram. At the junction of a

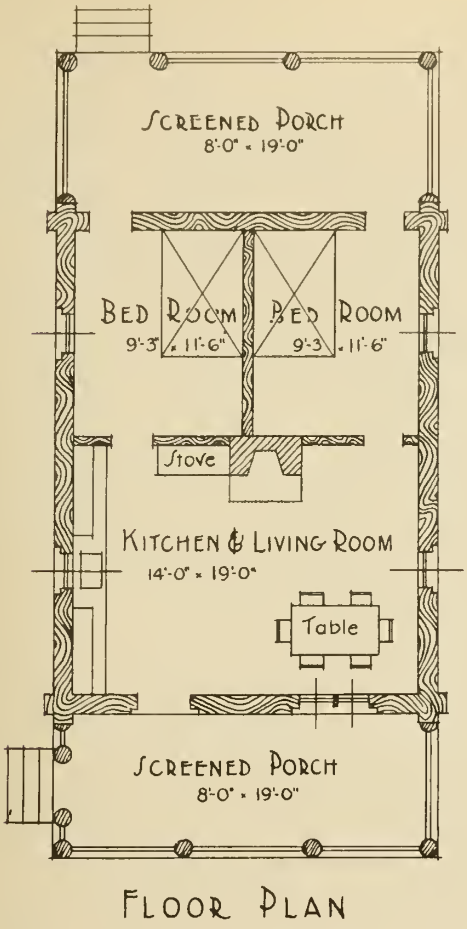


Figure 47-XVII. Three-room Log Cabin with Screened Porches

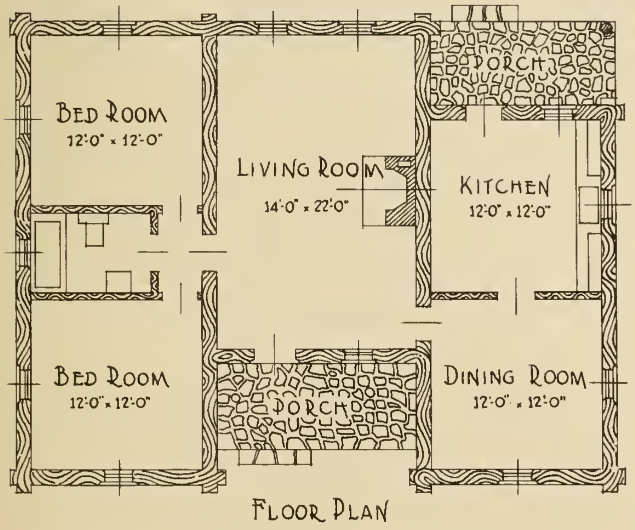


Figure 49-XVII. Five-room Log Cabin

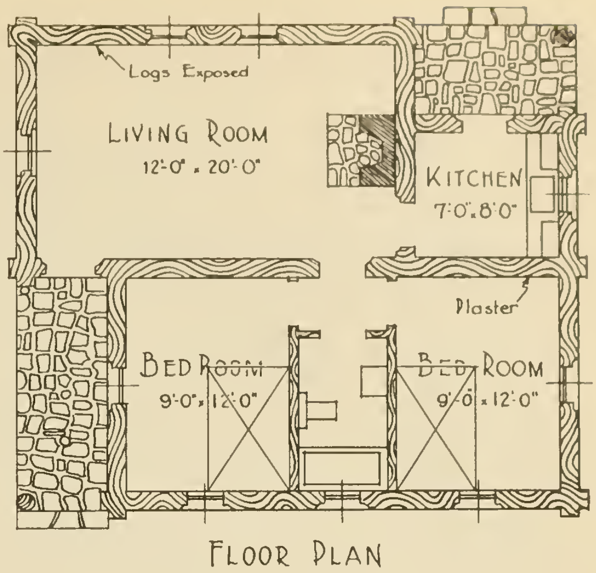


Figure 48-XVII. Four-room Log Cabin

river and a lake the stream is 1 1/4 miles wide and flows due east at the rate of 1/2 mile per hour. A boat leaves the dock at A on the south bank at 9:45 A.M. and sails N 30° E at the rate of 5 mi. per hr. (1) Where and at what time will the landing be made on the north bank? (2) The skipper is standing on the quarter-deck lookout when the boat shoves off. Ten minutes later he is in the engine room, 85 feet below the lookout. Where is the boat with respect to A when the skipper reaches the engine room? (3) What is the skipper's velocity with respect to point A?

6. Scale 1" = 50'. The floor plan of a foundry is 150' x 300' with the 300' dimension running east and west. The overhead tracks of a traveling crane are 65' above the floor. A large casting is on the floor at point A, which is in the southwest corner, 10 feet from either wall. The casting is picked up by the crane and is being moved vertically by a set of chain blocks at the rate of 12 1/2 feet per minute. The blocks, which are suspended from an overhead beam, are moving eastward, parallel to the beam, at the rate of 50 feet per minute. The overhead beam, traveling on parallel tracks at either end of the building, is moving north at the rate of 25 feet per minute. (1) Make a line drawing showing the plan and elevation of the foundry and locate on this drawing the position of the casting at the end of 4 minutes. (2) What is the velocity of the casting with respect to point A?

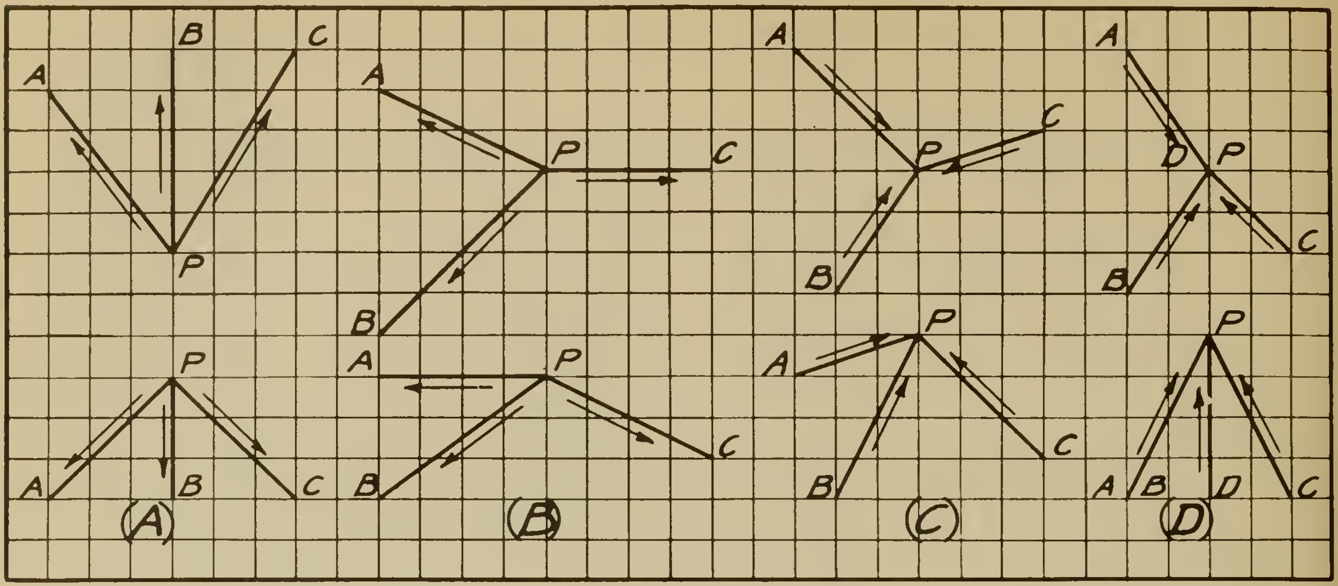


Figure 50-XVII. Concurrent, Noncoplanar Forces

7. Scale 1" = 20'. Force scale 1" = 1000 lb. Use a double space. The gin pole loading device of Figure 51-XVII has a load of one ton on the hooks. H = 30°. V = 60°. Use center lines to represent the mast, boom, boom line, and load line. Determine the stress in pounds in (1) the three guy wires, (2) mast, (3) boom, (4) boom line, and (5) load line.
8. Scale 1" = 1'-0". Force scale 1" = 1000 lb. Use a double space. The line drawing of Figure 52-XVII represents a hoist mounted on two tripods with casters on all six legs so it can be moved about. A load of one ton is suspended as shown. Only the essential dimensions are given. (1) Make a line drawing of the hoist in a two-view orthographic representation. (2) Determine the stress in pounds in the three legs of one of the tripods.

## Group 9-XVII. Mining Problems

1. On the map of Figure 53-XVII points of outcrop are located at 8, 3, and 4 in one wall of the vein, and point 5 is in the other wall. (1) What is the strike through 3 and the outcrop of the hanging wall? (2) What is the dip and thickness of the vein? A thin vein outcrops at the points 2, 11, and 10. (3) Show the strike through 11 and the outcrop and dip of the vein. (4) Determine the line of intersection of the thin vein with the hanging wall of the thicker vein.

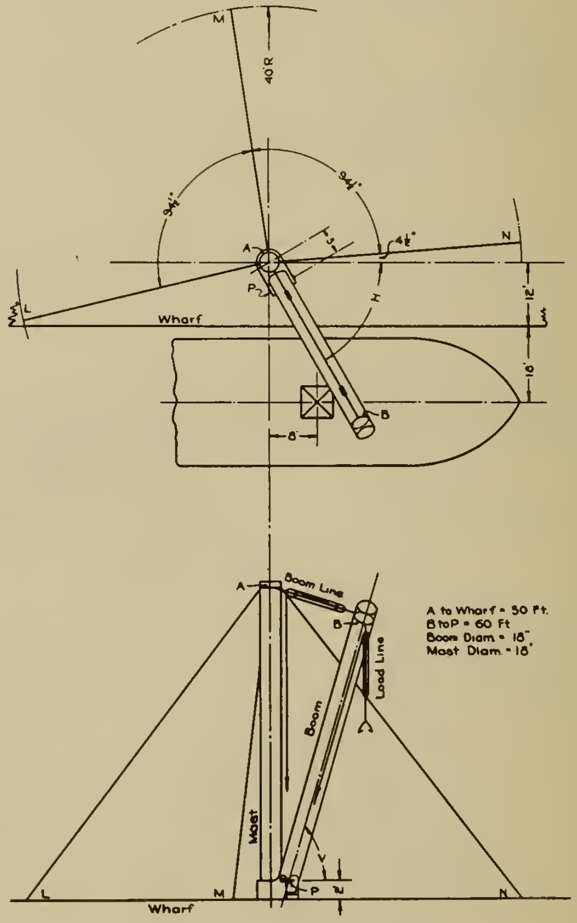


Figure 51-XVII. Gin Pole

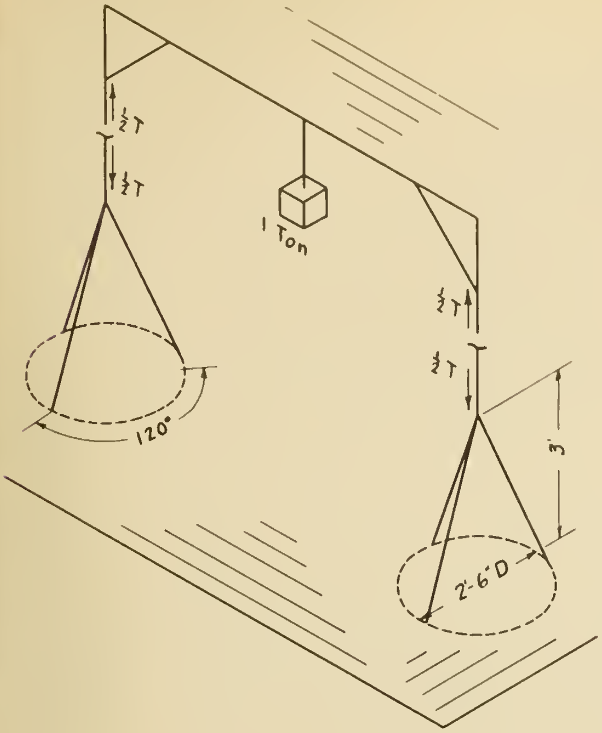


Figure 52-XVII. Movable Hoist

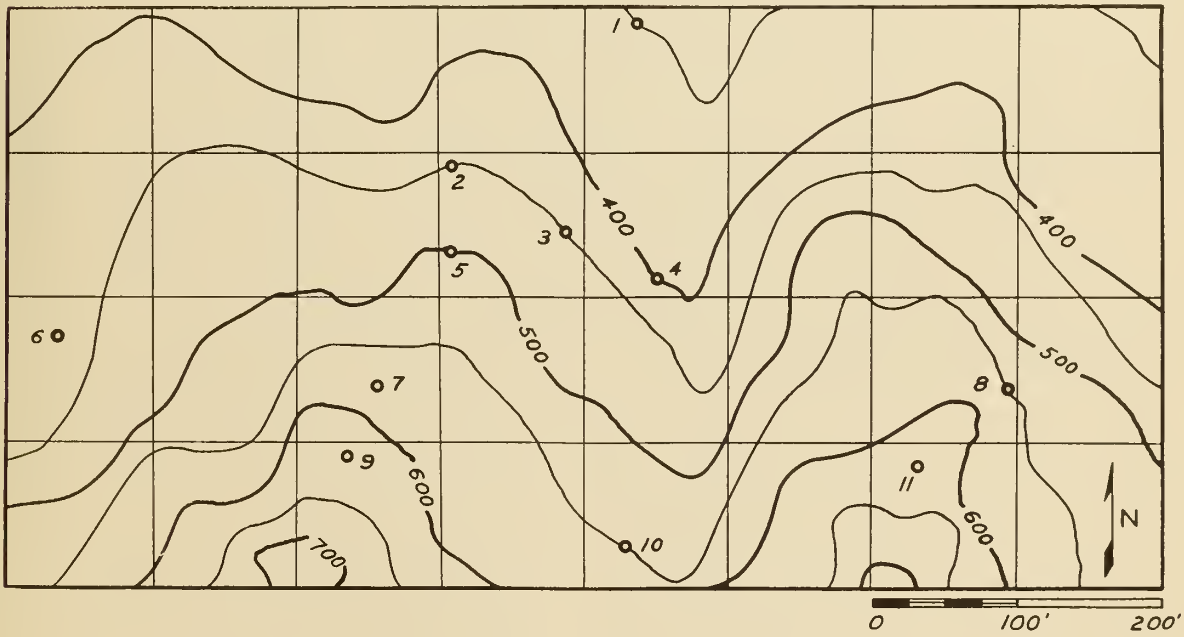


Figure 53-XVII. Contour Map of Dry Creek Gulch

2. A thin vein outcrops at point 11, Figure 53-XVII. The strike is S 10° E and the dip is 70° eastward. (1) Find the outcrop of the vein.

   Another vein has a strike of S 25° W through point 8 and a dip of 30° to the eastward. On the same contour with 8, but 20 feet westward, is the other wall of the vein. (2) Locate the outcrop of the hanging wall and determine the thickness of the vein.
3. Points 3, 2, and 7 are on the outcrop of a thin vein, Figure 53-XVII. Another thin vein outcrops at 4, 7, and 1. (1) Determine the strike and dip of the vein. (2) Locate the outcrop of each vein and the line of intersection of the two veins.
4. On the map of Figure 53-XVII a tunnel opening is located at point 9. Rock, with an angle of repose of 45°, is to be dumped at the level of 6 and at points on a radius of 20 feet from 6. (1) Show the outline of the resulting dump. Similar rock is to be taken from a shaft mouth at 11. The rock is to be dumped along a ridge so located that the dump will just reach the east and north boundaries of the map and will come within 20 feet of the bottom of the gulch on the opposite canyon wall. (2) Locate the ridge along which the dump is to be made.
5. The mouth of a shaft is located at point 10, Figure 53-XVII. Rock is to be dumped on the same level as the mouth of the shaft and at such a radius that the muck will just reach the north boundary of the map. The angle of repose is 40°. (1) Show the outline of the dump. (2) Locate a ridge at the 525 ft. elevation along which rock

is to be dumped east of the gulch so that the dump will not go beyond the east and north boundaries of the map. (3) Show the outline of the dump of (2).

6. Outcrops of a thick vein are located at points 6, 3, and 1 on the map of Figure 54-XVII. A point on the other wall of the vein is found on the 300 ft. level and straight west of point 3. (1) Determine the strike, dip, thickness of the vein, and outcrop of the hanging wall. The strike of a thin vein is S 40° W and passes through point 5. The dip is 58° westward. (2) Find the outcrop of the thin vein. (3) Locate the intersection of the hanging wall of the thick vein and the thin vein.

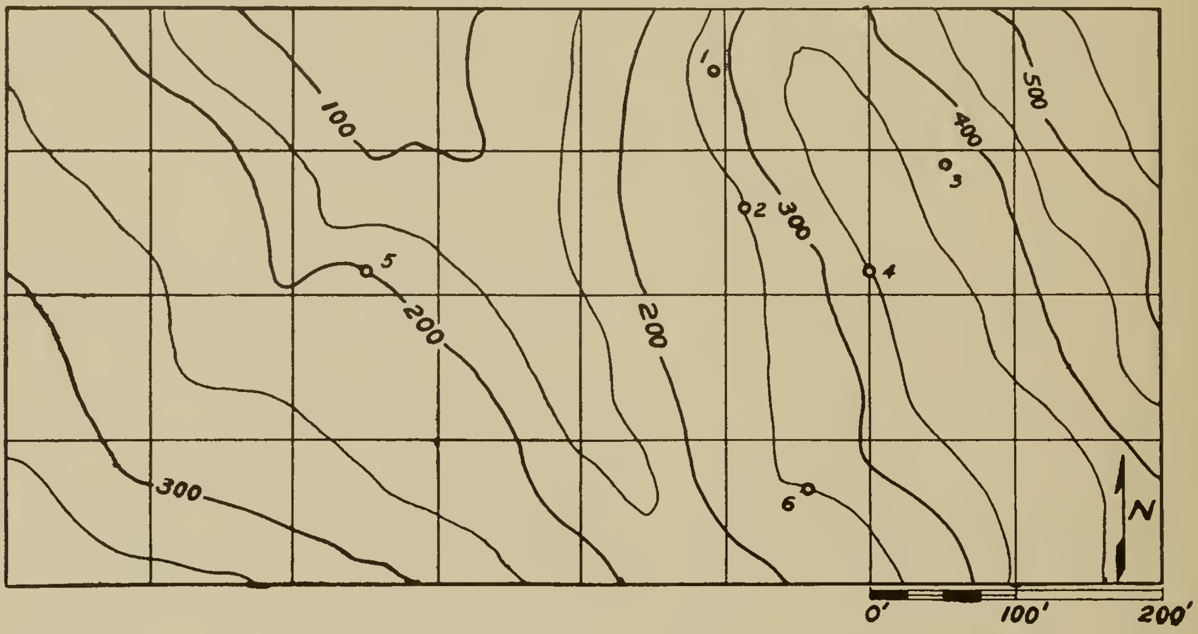


Figure 54-XVII. Contour Map of Upper Rattlesnake Gulch

## Group 10-XVII. Intersecting Cones by the Slicing Plane Method

1. The axes of two right circular cones intersect at the mid point of their axes. The axis of the larger cone is horizontal, and the vertex of the smaller cone is above the vertex of the larger cone. Angle between the axes is 75°. The altitude of each is 4 1/2". Diameters of bases equal 2 3/4" and 3 1/2". (1) Find the line of intersection between the two cones by the slicing plane method. (2) Make a development of the larger cone. Show holes in the pattern of the larger cone which will take the smaller cone. The surface of the smaller cone is not cut.
2. Same as exercise 1 above, except the angle between the axes is 90°.

## Group 11-XVII. Intersection of Cones and Cylinders by the Sphere Method

1. Do exercise 1, Gr. 10-XVII by the sphere method.
2. Do exercise 2, Gr. 10-XVII by the sphere method.
3. The axis of a right circular cone (which is vertical) and the axis of a right circular cylinder intersect at the mid point of the axis of the cone. The axis of the cylinder extends up and to the right and makes an angle of 75° with the axis of the cone. Altitude of cone is 4 1/2". Axis of cylinder is 3 3/4" from the point of intersection to the base of the cylinder. Diameter of cylinder is 2 1/4". Base of cone equals 3 1/2" in diameter. (1) Find the line of intersection between the two objects by the sphere method. (2) Make a development of the cone and a development of the cylinder.
4. Same as exercise 3 above, except angle between the axes equals 90°.
5. The axes of two right circular cylinders intersect at the mid point of their axes. The axis of the larger cylinder is horizontal and one end of the smaller cylinder is above the horizontal and lies to the right of the point of intersection. Altitude of each is 4 1/2". Diameter of the larger cylinder is 3 1/2", and the diameter of the smaller cylinder is 2 3/4". Angle between the axes is 75°. (1) Find the line of intersection between the two cylinders

by the sphere method. (2) Make a development of the larger cylinder. Show holes in the development of the larger cylinder which will just take the smaller cylinder. The surface of the smaller cylinder is not cut.

6. Same as exercise 5 above, except the angle between the axes is 90°.

Group 12-XVII. Tangent Planes

1. Figure 55-XVII-(A). Through point P draw planes tangent to the object. Show three principal views.
2. Figure 55-XVII-(A). Through element AB draw a plane tangent to the object. Show three principal views.
3. Figure 55-XVII-(A). Choose a point on the surface of the object. Through this point draw a plane tangent to the object. Show three principal views.
4. Figure 55-XVII-(B). Data same as exercise 1 above.
5. Figure 55-XVII-(B). Data same as exercise 2 above.
6. Figure 55-XVII-(B). Data same as exercise 3 above.
7. Figure 55-XVII-(C). Data same as exercise 1 above.
8. Figure 55-XVII-(C). Data same as exercise 2 above.
9. Figure 55-XVII-(C). Data same as exercise 3 above.
10. Figure 55-XVII-(D). Data same as exercise 1 above.
11. Figure 55-XVII-(D). Data same as exercise 2 above.
12. Figure 55-XVII-(D). Data same as exercise 3 above.
13. Figure 55-XVII-(E). Through element AB draw planes tangent to the sphere. Show an auxiliary view and three principal views.
14. Figure 55-XVII-(E). Choose a point on the surface of the sphere. Through this point draw a plane tangent to the sphere. Show an auxiliary view and three principal views.

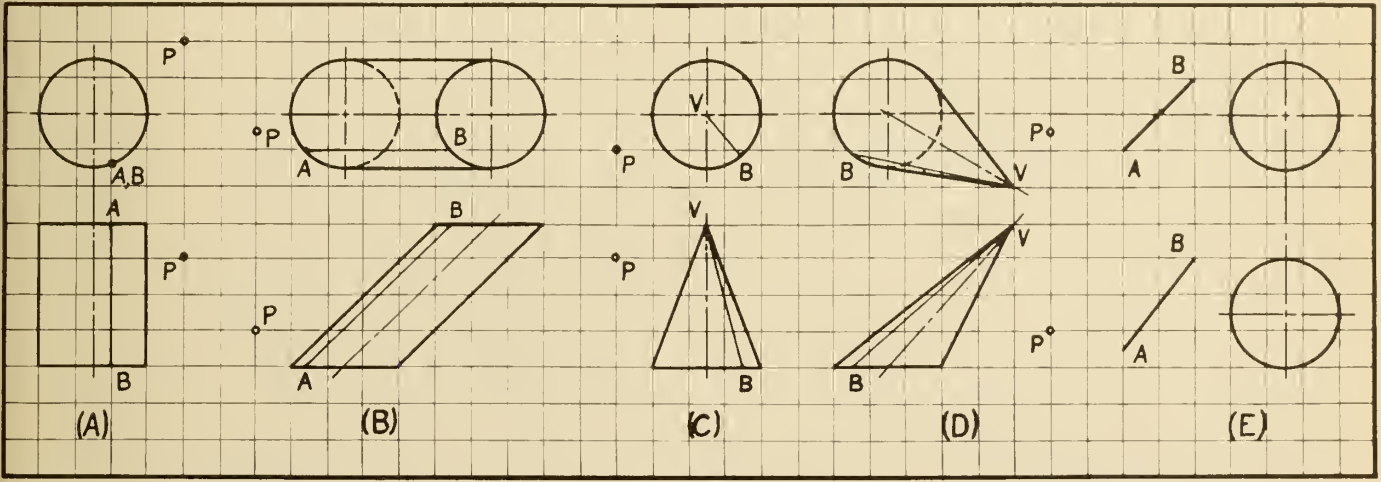


Figure 55-XVII. Tangent Plane Exercises

Group 13-XVII. Streamlining

1. The drawings of Figure 29-XVII show the front half of an airplane pontoon. Point O is 9'-6" in front of the vertical plane ABL. Width, AB, is 9'-9". Horizontal plane AOB is 5'-3" above the bottom of the pontoon. Vertical diameter of the pontoon in plane ABL is 8'-3". (1) Design a pontoon similar to the one shown. Use no circular arcs. (2) Make developments of the three sections.
2. Design the rear half of the pontoon of exercise 1 above. The rear half of the pontoon is much sharper than the forward portion, forming, in general, a "tear drop" with the blunter point of the "tear drop" forward.
3. The drawings of Figure 30-XVII show the forebody of the port side of a boat. (Half drawing is shown.) Total length 37'-9". Elevation at center of boat is 7'-6". Width at the center of the boat is 10'-9". Design the surface of the starboard forebody of a boat similar to the one shown. Check for fair surface.
4. Using the data given in exercise 3 above, design the port side of the afterbody of a boat showing three principal views. Check

for fair surface. The forebody of the boat is much blunter than the afterbody. In general, the blunter portion of the "tear drop" will form the forebody of the boat.

## Group 14-XVII. Machine Drawing (See Shop Terms and Practices)

1. The instructor will assign each student a piece of mechanism or machine part to be used as a drawing model. (1) Make an assembly view of the object (pictorial or orthographic as assigned). Section the assembly, break the surface of the object, or draw subassemblies, if necessary to show at least a part of each piece. See Figure 44-XVII. (2) Number each piece. (3) Make separate detail drawings of each piece. (4) Make a bill of material, notes, title, etc. The first plate is to be drawn free hand, the object turned in at the drawing office, and the free-hand plate used to make a plate with instruments. Rearrange the free-hand plate if in so doing the instrument plate is improved. (5) Make a tracing and a print.

## Group 15-XVII. Miscellaneous

1. A railroad bears S 68° W and passes through point 2, Figure 54-XVII. The grade is zero and the bed is 35 feet wide. The walls of the cuts will stand at 48°. The angle of repose of the rock in the fills is 40°. (1) Locate the railroad bed and the limits of the cuts and fills. (2) Locate a trail, 14% grade, starting at the 200 ft. elevation on the south boundary just west of the bed of the gulch and extending to point 4. Give the bearing of each piece of tangent and total length of trail.
2. Scale 1/8" = 1'-0". The concrete for the abutments and wing walls have been poured for the bridge illustrated in Figure 56-XVII.
3. Scale 1/4" = 1'-0". A gravity abutment for a beam bridge is shown in Figure 57-XVII. The reinforcing steel and some of the details are omitted. Reproduce the plan and front elevation (omit sectional views). Find: (1) The line of intersection between the inclined face of the abutment and the inclined face of the wing wall. (2) The lines of intersection between the inclined face of the wing wall and the bridge seat (a horizontal surface). Show coordinates for the lines just determined. Only a part of one line of these last two intersecting surfaces is shown. The beams will rest on top of the abutment and support the deck. Forms have been placed for the beams. Line MN is a brace which is anchored to some point on the bank and to one of the beam forms. It is level and parallel to the stream face of the wing wall. From some point J which lies in the bank face of the wing wall, and above the forms, a brace is fastened to a form stud and is perpendicular to the surface of the inclined face. The brace is fastened to MN at point L, which is 8'-6" from M. Give: (1) the coordinates for J and (2) the length of JL.

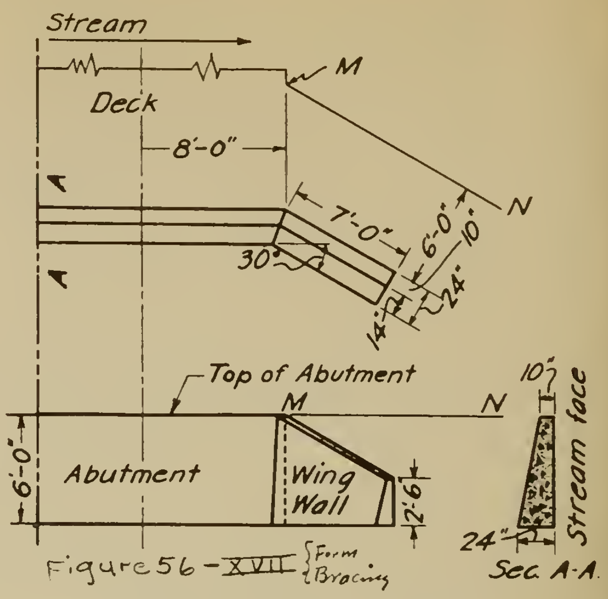


Figure 56-XVII. Form Bracing

4. Scale 1/4" = 1'-0". See Figure 57-XVII. (1) Give the angle in degrees between the inclined faces of the abutment and the wing wall.
5. Scale 1/4" = 1'-0". See Figure 57-XVII. (1) Give the angle in degrees between the concrete surface at the end of the bridge seat (which lies in a profile plane) and the inclined surface of the wing wall.
6. Scale 1/8" = 1'-0". See Figure 56-XVII. (1) Give the angle in degrees between the inclined faces of the abutment and the wing wall.
7. Scale 1" = 40'. Use a double space. Copy the map of Figure 58-XVII, showing the relocation of a small creek. The slope of natural ground surface is toward the creek on either side, as indicated, and is considered constant. The highway grade at the intersection is zero, as shown. A

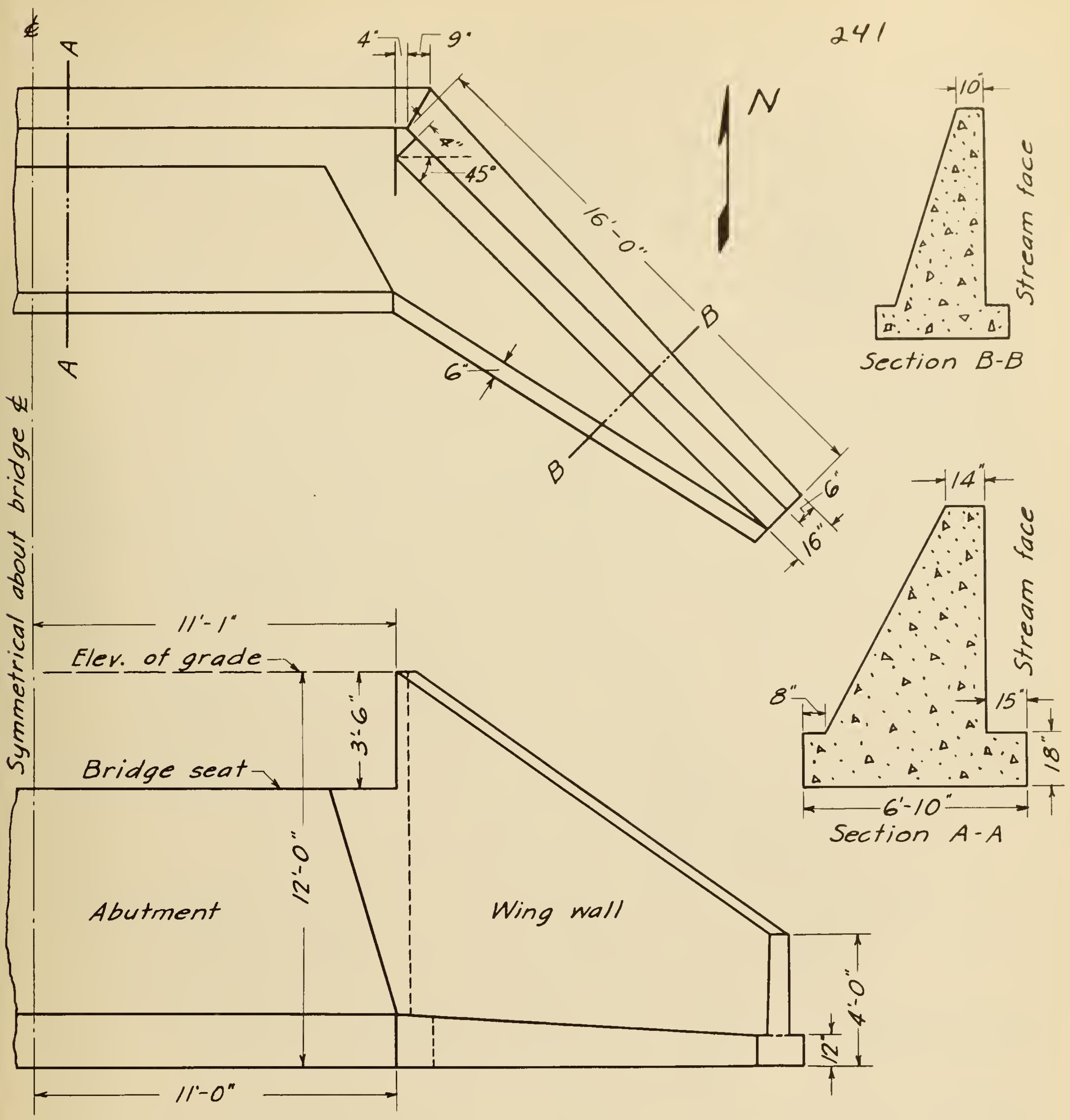


Figure 57-XVII. Gravity Abutment for Beam Bridge

"station" is equal to 100'. The average slope of the creek in the old location is S = 2 1/2 : 1000, as indicated. To determine the length of culvert, measure 100' on either side of the center of the intersection and parallel to the center line of the road, thus locating the lines on which A and B lie. The side slopes of the highway and the ground surface intersect on the line just located, which determines the exact location of points A and B. The center lines of the side drains are 3 1/2'

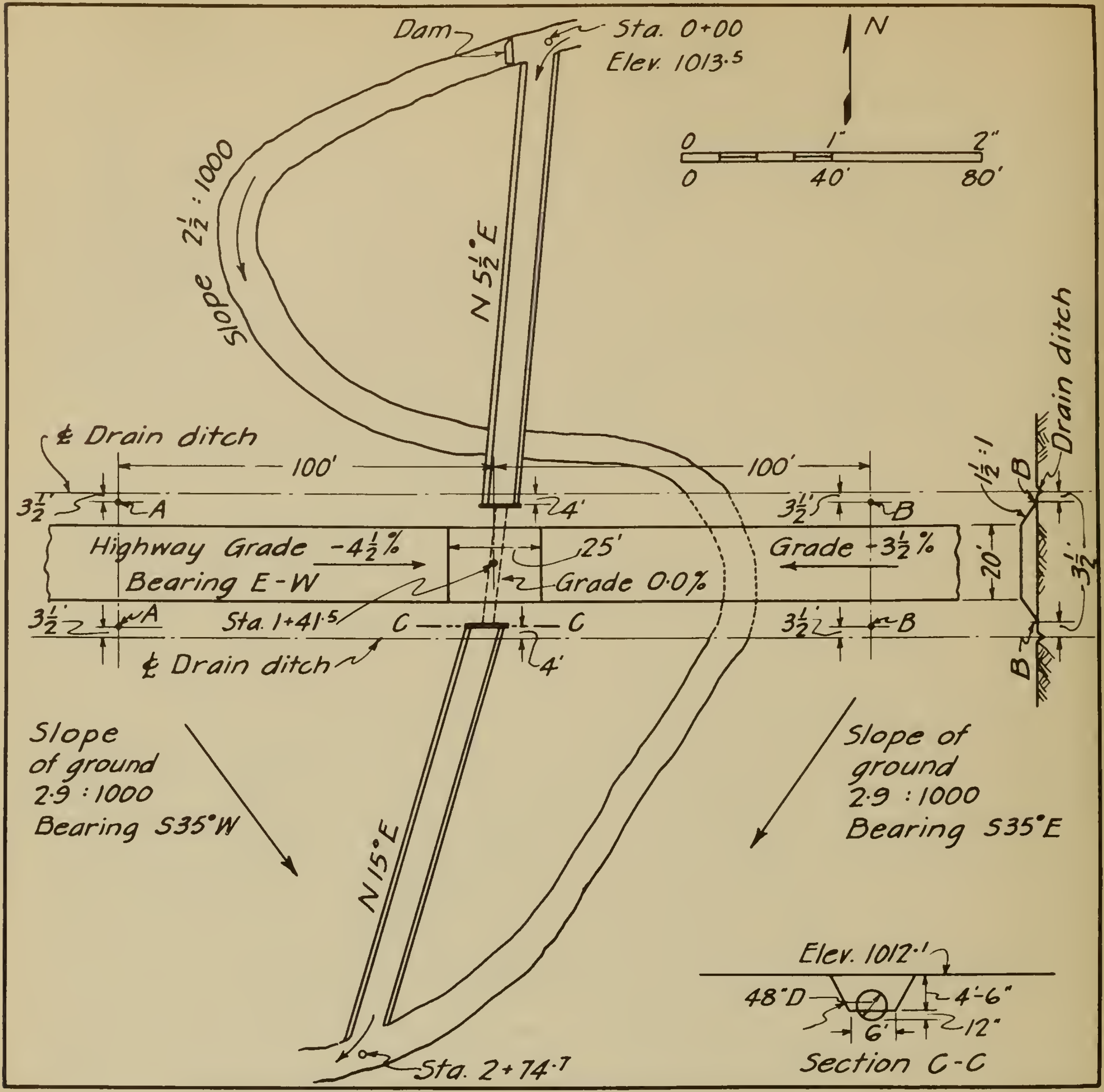


Figure 58-XVII. Drainage Realignment

from A and B and parallel to the center of the road. The outside head walls of the culvert are 4' from the center lines of the side drains. (1) What is the length of span of the culvert? (2) What is the stream slope (gradient) of the new location? (3) Station elevations are given on the grade line. What is the number of cubic yards of excavation for the new location?

8. Scale 1/16" = 1'-0". Force scale 1" = 1000 lb. Use a double space. Using center lines for the mast, boom, boom line, and load line, make a drawing of the gin pole of Figure 51-XVII. Show the hatchway, but omit the outline of the boat. Determine: (1) Angles V and H when a load is being hoisted through the center of the hatch. (2) Slope of the guy wire AL and slope of plane ALM. (3) When a load of 1500 pounds is being hoisted from the hold of the boat, what is the stress in pounds

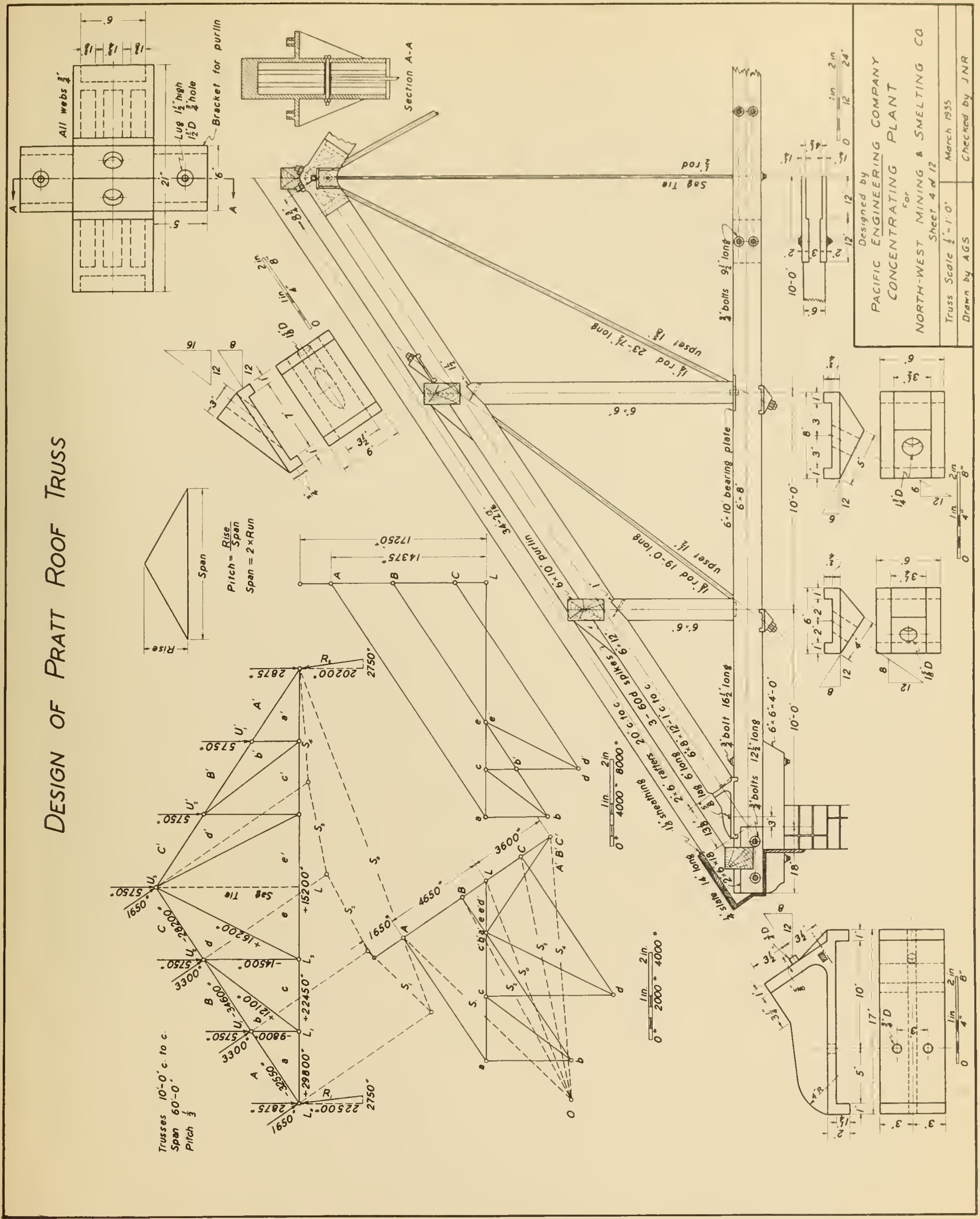


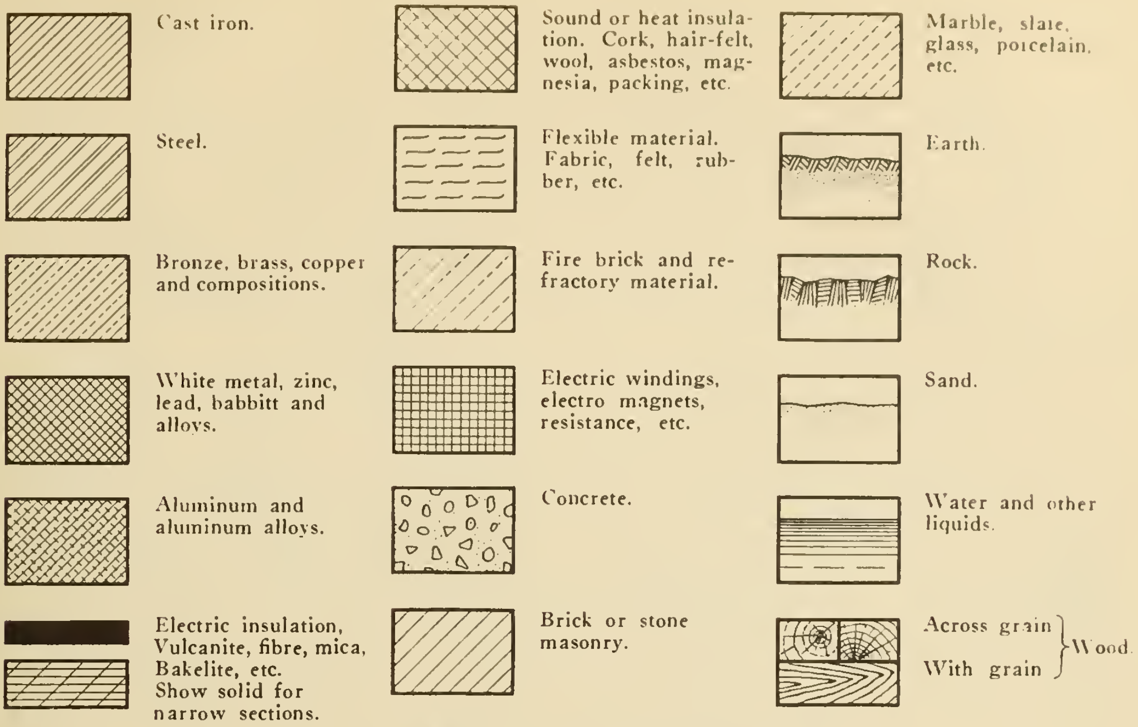
Figure 59-XVII. Pratt Roof Truss

in each of the three guy wires, the mast, the boom line, the boom, and the load line?

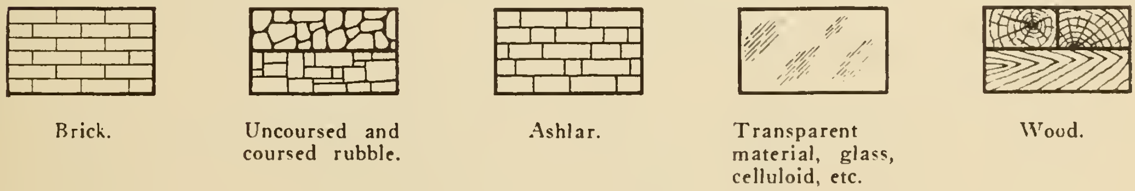
9. Scale 1/4" = 1'-0". Use a double space. (1) Using center lines to represent the various members, make a drawing of only the truss shown in Figure 59-XVII. (2) Make a bill of material for only one complete truss (omit, rafters, purlin, etc.), giving lengths and sizes of members. (3) An elevation and bottom (plan) view is shown of the cast-iron bracket for joint $L_0$. Make a complete set of dimensioned drawings of the bracket composed of elevation, top (plan), and auxiliary views.
10. Scale 1 1/2" = 1'-0". Make a set of dimensioned drawings composed of plan (top), front elevation, auxiliary, and sectional views of the cast-iron bracket at joint $U_3$, Pratt roof truss, Figure 59-XVII.
11. Scale 1/2" = 1'-0". Force scale 1" = 3000 lb. Use a double space. The reactions at the two ends of the Pratt roof truss, Figure 59-XVII, are 15,000 pounds each, acting vertically upward. A dead load of 2500 pounds acts vertically downward at joint $L_0$. A similar load of 5000 pounds is acting at joint $U_1$. Determine the stress in pounds in the various members leading to joints (1) $L_0$, (2) $U_1$, and (3) $L_1$, due to the above loading. See Figure 17-XVII.
12. Scale 1/2" = 1'-0". Force scale 1" = 5000 lb. Use a double space. The Warren truss of Figure 17-XVII consists of 4 panels with a total span of 40 feet. The truss is 15 feet high. P = 10,000 pounds. Determine the stress in pounds in the various members leading to joints (1) $L_0$, (2) $U_1$, and (3) $L_1$.

# APPENDIX

In compiling the following engineering data and illustrations, the recommendations of the American Standards Association were followed where they were applicable.


Cast iron.
Steel.
Bronze, brass, copper and compositions.
White metal, zinc, lead, babbitt and alloys.
Aluminum and aluminum alloys.
Electric insulation, Vulcanite, fibre, mica, Bakelite, etc. Show solid for narrow sections.
Sound or heat insulation. Cork, hair-felt, wool, asbestos, magnesia, packing, etc.
Flexible material. Fabric, felt, rubber, etc.
Fire brick and refractory material.
Electric windings, electro magnets, resistance, etc.
Concrete.
Brick or stone masonry.
Marble, slate, glass, porcelain, etc.
Earth.
Rock.
Sand.
Water and other liquids.
Across grain
With grain
Wood.

SYMBOLS FOR SECTION LINING


Brick.
Uncoursed and coursed rubble.
Ashlar.
Transparent material, glass, celluloid, etc.
Wood.

SYMBOLS FOR OUTSIDE VIEWS

Figure 1-A. Conventions for Materials in Section and Outside Views (American Standards Association)

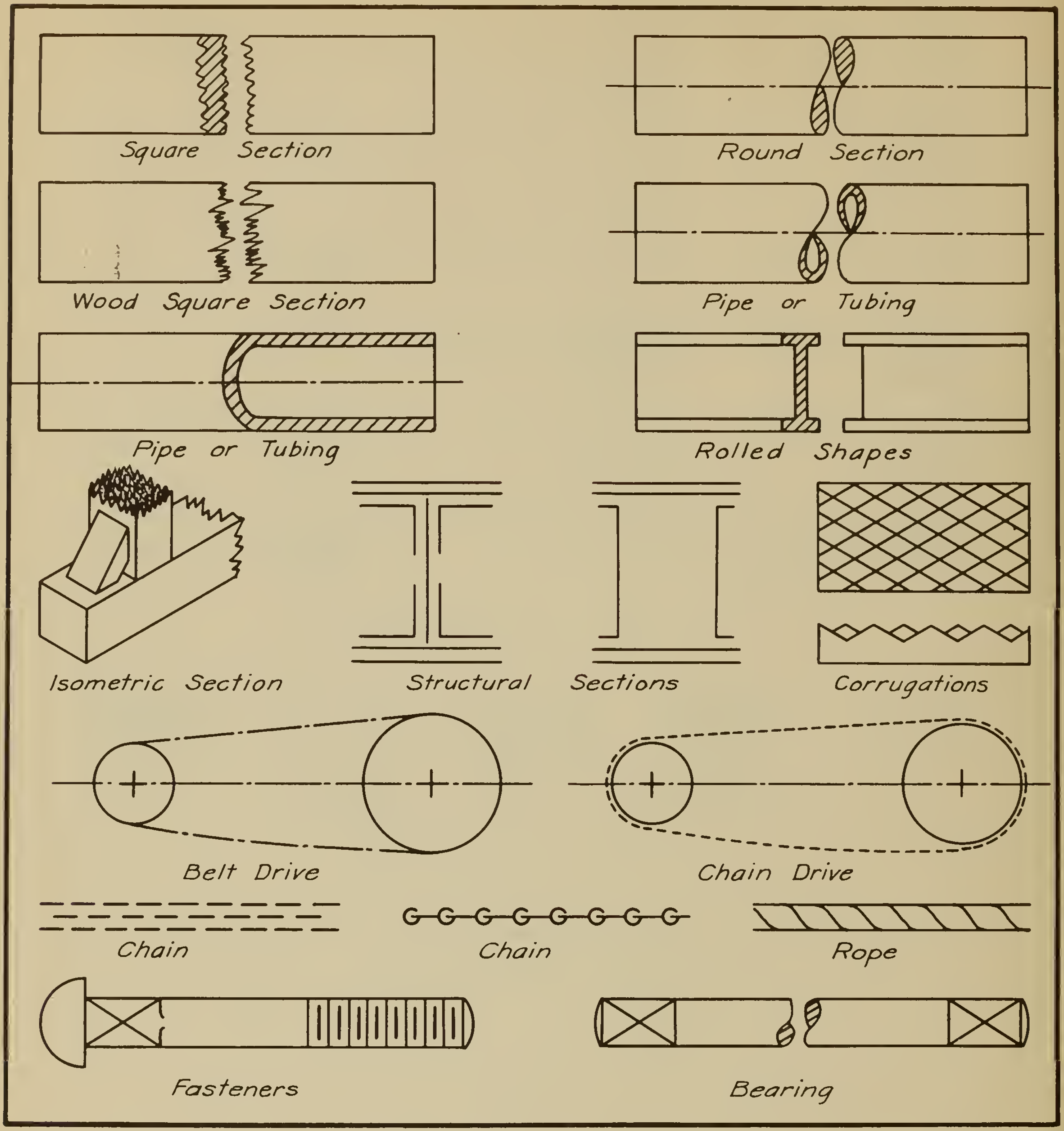


Figure 2-A. Conventional Breaks and Symbols

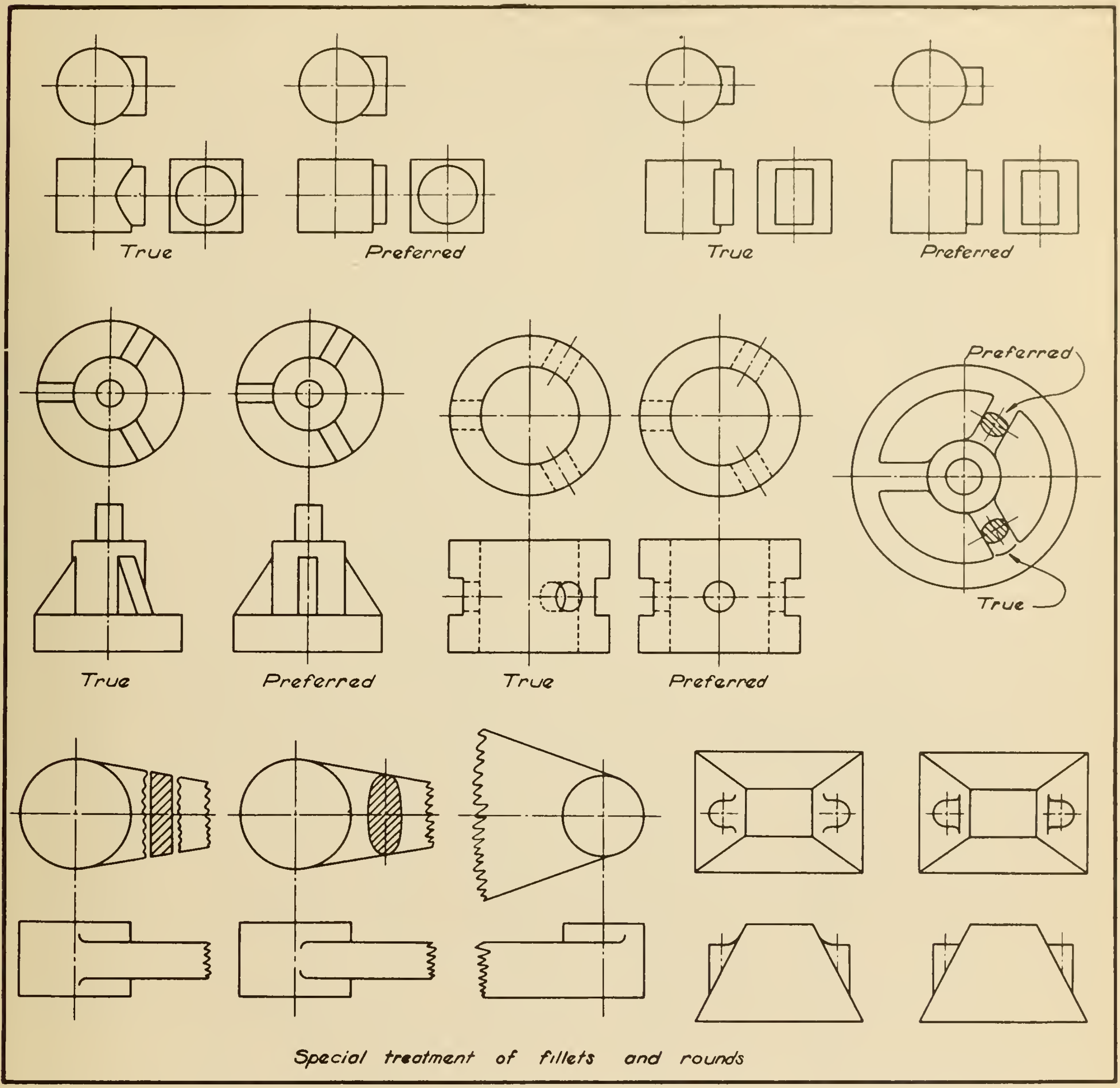


Figure 3-A. Conventional Intersections and Idioms of Drawing

TABLE I

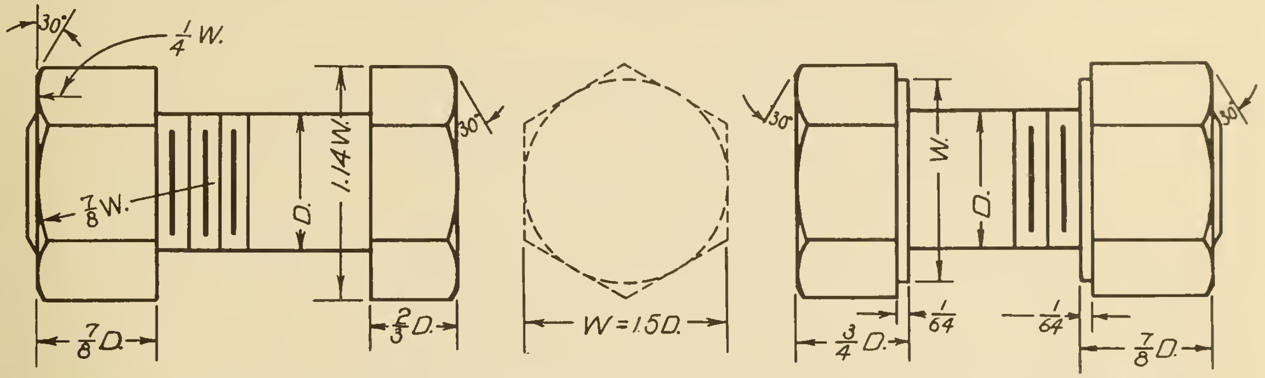
## AMERICAN NATIONAL COARSE, FINE, AND SPECIAL THREAD SERIES

| Size No. | Diameter in inches | Threads per in. | |
|---|---|---|---|
| 1 | 0.0730 | 64 | Coarse Series (NC) |
| 2 | 0.0860 | 56 | |
| 3 | 0.0990 | 48 | |
| 4 | 0.1120 | 40 | |
| 5 | 0.1250 | 40 | |
| 6 | 0.1380 | 32 | |
| 8 | 0.1640 | 32 | |
| 10 | 0.1900 | 24 | |
| 12 | 0.2160 | 24 | |
| 0 | 0.0600 | 80 | Fine Series (NF) |
| 1 | 0.0730 | 72 | |
| 2 | 0.0860 | 64 | |
| 3 | 0.0990 | 56 | |
| 4 | 0.1120 | 48 | |
| 5 | 0.1250 | 44 | |
| 6 | 0.1380 | 40 | |
| 8 | 0.1640 | 36 | |
| 10 | 0.1900 | 32 | |
| 12 | 0.2160 | 28 | |

| Diameter | Threads per inch | | |
|---|---|---|---|
| | Coarse NC | Fine NF | Special NS |
| 1/4 | 20 | 28 | 36 |
| 5/16 | 18 | 24 | 32 |
| 3/8 | 16 | 24 | 32 |
| 7/16 | 14 | 20 | 28 |
| 1/2 | 13 | 20 | 28 |
| 9/16 | 12 | 18 | 24 |
| 5/8 | 11 | 18 | 24 |
| 3/4 | 10 | 16 | 20 |
| 7/8 | 9 | 14 | 20 |
| 1 | 8 | 14 | 20 |
| 1 1/8 | 7 | 12 | 18 |
| 1 1/4 | 7 | 12 | 18 |
| 1 1/2 | 6 | 12 | 18 |
| 1 3/4 | 5 | 12 | 16 |
| 2 | 4 1/2 | 12 | 16 |
| 2 1/4 | 4 1/2 | 12 | 16 |
| 2 1/2 | 4 | 12 | 16 |
| 2 3/4 | 4 | 12 | 16 |
| 3 | 4 | 10 | 16 |
| over 3 to 6 | .... | 10 | 16 |
| over 6 | .... | 8 | 16 |

## TABLE II

## AMERICAN NATIONAL SQUARE AND HEXAGONAL BOLT HEADS AND NUTS
(THREADS ARE COARSE SERIES)



*Am. Nat'l. rough and semi-finished hexagonal head bolt.*

*For sizes 3/4" and under see table Am. Nat'l. finished hexagonal head bolt*

| Diam., D | Bolt Heads | | | | Nuts | |
|---|---|---|---|---|---|---|
| | Rough and semi-finished | | Finished | | Both rough and finished | |
| | W | H | W | H | W | T |
| 1/4 | 3/8 | 11/64 | 7/16 | 3/16 | 7/16 | 7/32 |
| 5/16 | 1/2 | 13/64 | 9/16 | 15/64 | 9/16 | 17/64 |
| 3/8 | 9/16 | 1/4 | 5/8 | 9/32 | 5/8 | 21/64 |
| 7/16 | 5/8 | 19/64 | 3/4 | 21/64 | 3/4 | 3/8 |
| 1/2 | 3/4 | 21/64 | 13/16 | 3/8 | 13/16 | 7/16 |
| 9/16 | 7/8 | 3/8 | 7/8 | 27/64 | 7/8 | 31/64 |
| 5/8 | 15/16 | 27/64 | 15/16 | 15/32 | 15/16 | 35/64 |
| 3/4 | 1 1/8 | 1/2 | 1 1/8 | 9/16 | 1 1/8 | 21/32 |
| 7/8 | 1 5/16 | 19/32 | 1 5/16 | 21/32 | 1 5/16 | 49/64 |
| 1 | 1 1/2 | 21/32 | 1 1/2 | 3/4 | 1 1/2 | 7/8 |
| 1 1/8 | 1 11/16 | 3/4 | 1 11/16 | 27/32 | 1 11/16 | 1 |
| 1 1/4 | 1 7/8 | 27/32 | 1 7/8 | 15/16 | 1 7/8 | 1 3/32 |
| 1 1/2 | 2 1/4 | 1 | 2 1/4 | 1 1/8 | 2 1/4 | 1 5/16 |
| 1 3/4 | 2 5/8 | 1 5/32 | 2 5/8 | 1 5/16 | 2 5/8 | 1 17/32 |
| 2 | 3 | 1 11/32 | 3 | 1 1/2 | 3 | 1 3/4 |
| 2 1/4 | 3 3/8 | 1 1/2 | 3 3/8 | 1 11/16 | 3 3/8 | 1 31/32 |
| 2 1/2 | 3 3/4 | 1 21/32 | 3 3/4 | 1 7/8 | 3 3/4 | 2 3/16 |
| 2 3/4 | 4 1/8 | 1 53/64 | 4 1/8 | 2 1/16 | 4 1/8 | 2 13/32 |
| 3 | 4 1/2 | 2 | 4 1/2 | 2 1/4 | 4 1/2 | 2 5/8 |

## TABLE III

## V-SHARP THREADS

| Diameter | Threads per inch | Diameter | Threads per inch | Diameter | Threads per inch | Diameter | Threads per inch | Diameter | Threads per inch |
|---|---|---|---|---|---|---|---|---|---|
| 1/16 | 72 | 9/16 | 12 | 1 1/4 | 7 | 1 15/16 | 4 1/2 | 3 5/8 | 3 1/4 |
| 3/32 | 56 | 5/8 | 11 | 1 5/16 | 7 | 2 | 4 1/2 | 3 3/4 | 3 |
| 1/8 | 40 | 11/16 | 11 | 1 3/8 | 6 | 2 1/8 | 4 1/2 | 3 7/8 | 3 |
| 5/32 | 32 | 3/4 | 10 | 1 7/16 | 6 | 2 1/4 | 4 1/2 | 4 | 3 |
| 3/16 | 24 | 13/16 | 10 | 1 1/2 | 6 | 2 3/8 | 4 1/2 | 4 1/2 | 2 7/8 |
| 7/32 | 24 | 7/8 | 9 | 1 9/16 | 6 | 2 1/2 | 4 | 4 1/2 | 2 3/4 |
| 1/4 | 20 | 15/16 | 9 | 1 5/8 | 5 | 2 5/8 | 4 | 4 3/4 | 2 5/8 |
| 5/16 | 18 | 1 | 8 | 1 11/16 | 5 | 2 3/4 | 4 | 5 | 2 1/2 |
| 3/8 | 16 | 1 1/16 | 8 | 1 3/4 | 5 | 2 7/8 | 4 | | |
| 7/16 | 14 | 1 1/8 | 7 | 1 13/16 | 5 | 3 | 3 1/2 | | |
| 1/2 | 12 | 1 3/16 | 7 | 1 7/8 | 4 1/2 | 3 1/8 | 3 1/2 | | |
| | | | | | | 3 1/4 | 3 1/2 | | |
| | | | | | | 3 3/8 | 3 1/4 | | |
| | | | | | | 3 1/2 | 3 1/4 | | |

## TABLE IV

## DIMENSIONS OF STANDARD STEEL AND WROUGHT-IRON PIPE

| Nominal inside diameter in inches | Actual outside diameter in inches | Actual inside diameter in inches | Internal area in square inches | Threads per inch | Actual inside diameter inches | |
|---|---|---|---|---|---|---|
| | | | | | Extra heavy | Double extra |
| 1/8 | .405 | .270 | .057 | 27 | .205 | |
| 1/4 | .540 | .364 | .104 | 18 | .294 | |
| 3/8 | .675 | .494 | .191 | 13 | .421 | |
| 1/2 | .840 | .623 | .304 | 14 | .542 | .244 |
| 3/4 | 1.05 | .824 | .533 | 14 | .736 | .422 |
| 1 | 1.315 | 1.048 | .861 | 11 1/2 | .951 | .587 |
| 1 1/4 | 1.66 | 1.38 | 1.496 | 11 1/2 | 1.272 | .885 |
| 1 1/2 | 1.9 | 1.61 | 2.036 | 11 1/2 | 1.494 | 1.088 |
| 2 | 2.375 | 2.067 | 3.356 | 11 1/2 | 1.933 | 1.491 |
| 2 1/2 | 2.875 | 2.468 | 4.78 | 8 | 2.315 | 1.755 |
| 3 | 3.5 | 3.067 | 7.383 | 8 | 2.892 | 2.284 |
| 3 1/2 | 4 | 3.548 | 9.887 | 8 | 3.358 | 2.716 |
| 4 | 4.5 | 4.026 | 12.73 | 8 | 3.818 | 3.136 |
| 4 1/2 | 5 | 4.508 | 15.961 | 8 | 4.28 | 3.564 |
| 5 | 5.563 | 5.045 | 19.986 | 8 | 4.813 | 4.063 |
| 6 | 6.625 | 6.065 | 28.89 | 8 | 5.751 | 4.875 |
| 7 | 7.625 | 7.023 | 38.738 | 8 | 6.625 | 5.875 |
| 8 | 8.625 | 7.982 | 50.027 | 8 | 7.625 | 6.875 |
| 9 | 9.625 | 8.937 | 62.72 | 8 | 8.625 | |
| 10 | 10.75 | 10.019 | 78.823 | 8 | 9.75 | |

## TABLE V

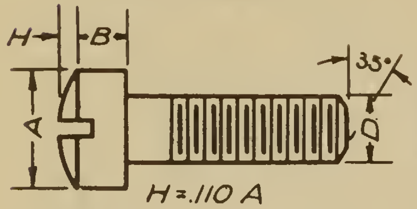
## AMERICAN NATIONAL FINISHED HEXAGONAL CAP SCREW HEADS
(THREADS ARE COARSE SERIES)

| Diameter | Width across flats W | Height of head H | Diameter | Width across flats W | Height of head H | Diameter | Width across flats W | Height of head H |
|---|---|---|---|---|---|---|---|---|
| 1/4 | 7/16 | 3/16 | 1/2 | 3/4 | 3/8 | 7/8 | 1 1/8 | 21/32 |
| 5/16 | 1/2 | 15/64 | 9/16 | 13/16 | 27/64 | 1 | 1 5/16 | 3/4 |
| 3/8 | 9/16 | 9/32 | 5/8 | 7/8 | 15/32 | 1 1/8 | 1 1/2 | 27/32 |
| 7/16 | 5/8 | 21/64 | 3/4 | 1 | 9/16 | 1 1/4 | 1 11/16 | 15/16 |

## TABLE VI

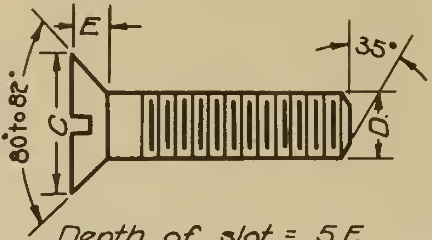
### SLOTTED HEAD CAP SCREWS
(THREADS ARE COARSE SERIES)

*Fillister Head*



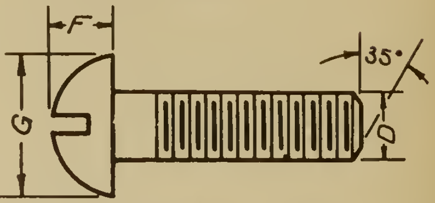
*Depth of slot = .5(B+H)*
*Min. Length of Thds. = 1.5D+.25*
*Width of slots = .160 D+.024*

*Flat Head*



*Depth of slot = .5 E*

*Button Head*



*Depth of slot = .66 F*
*Shape of head is semi-elliptical*

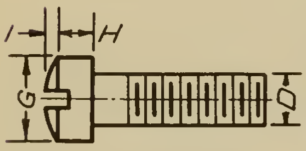
*Screw Lengths: $\frac{1}{4}$" to 1" = $\frac{1}{8}$ D., 1" to 4" = $\frac{1}{4}$ D., 4" to 6" = $\frac{1}{2}$ D.*

| D Diameter of screw | 1/4 | 5/16 | 3/8 | 7/16 | 1/2 | 9/16 | 5/8 | 3/4 | 7/8 | 1 |
|---|---|---|---|---|---|---|---|---|---|---|
| A | 3/8 | 7/16 | 9/16 | 5/8 | 3/4 | 13/16 | 7/8 | 1 | 1 1/8 | 1 15/16 |
| B | 11/64 | 13/64 | 1/4 | 19/64 | 21/64 | 3/8 | 27/64 | 1/2 | 19/32 | 21/32 |
| C | 1/2 | 5/8 | 3/4 | 13/16 | 7/8 | 1 | 1 1/8 | 1 3/8 | | |
| E | .146 | .183 | .220 | .220 | .220 | .256 | .293 | .366 | | |
| F | 7/16 | 9/16 | 5/8 | 3/4 | 13/16 | 15/16 | 1 | 1 1/4 | | |
| G | 3/16 | 15/64 | 1/4 | 5/16 | 21/64 | 25/64 | 7/16 | 17/32 | | |

## TABLE VII

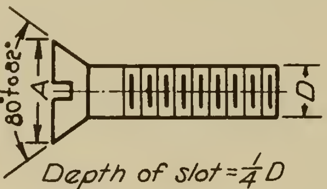
### MACHINE SCREWS
(THREADS ARE COARSE SERIES OR FINE SERIES)

*Fillister Head*



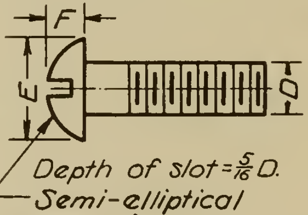
*Depth of slot = $\frac{7}{16}$ D.*

*Flat Head*



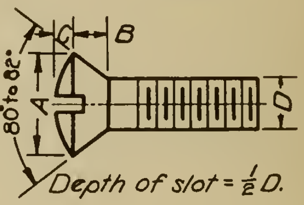
*Depth of slot = $\frac{1}{4}$ D*

*Button Head*



*Depth of slot = $\frac{5}{16}$ D.*
*Semi-elliptical*

*Oval Head*



*Depth of slot = $\frac{1}{2}$ D.*

*Nominal width of slots for all heads = $\frac{3}{16}$ D.*

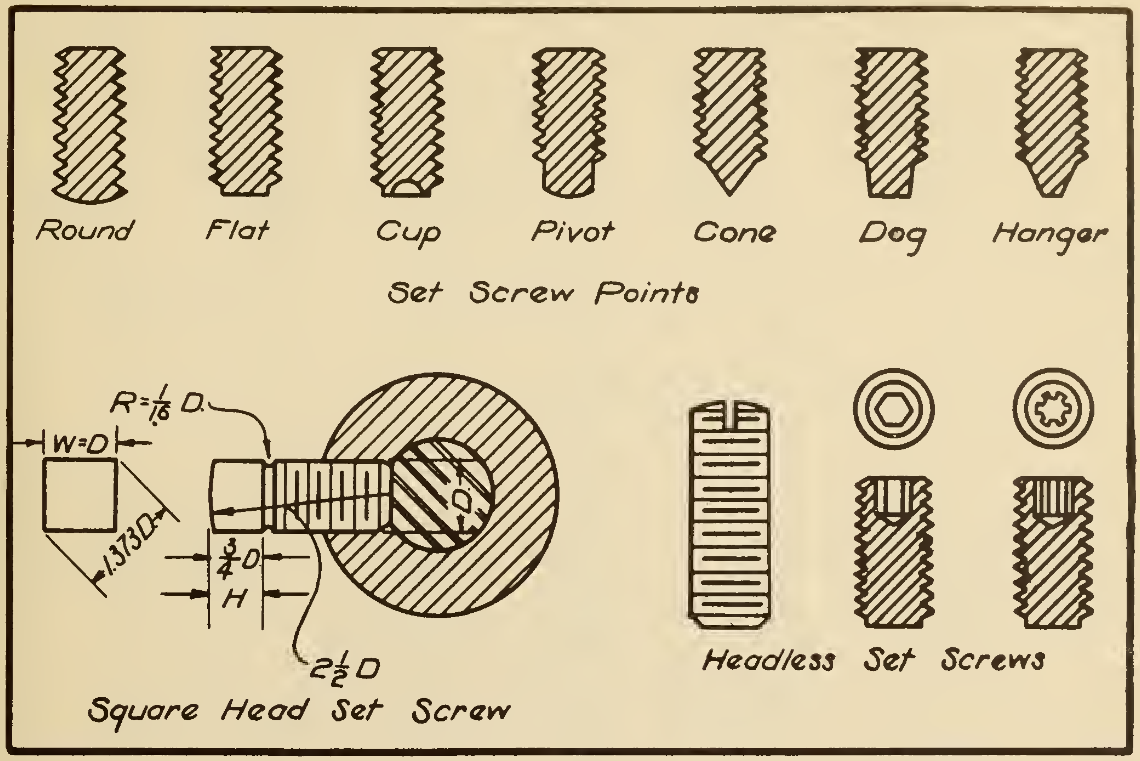
| Nominal size No. | 2 | 3 | 4 | 5 | 6 | 8 | 10 | 12 | 1/4 | 5/16 | 3/8 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| D = Diameter | .086 | .099 | .112 | .125 | .138 | .164 | .190 | .216 | .250 | .3125 | .375 |
| A | .164 | .190 | .216 | .242 | .268 | .320 | .372 | .424 | .492 | .618 | .742 |
| B | .046 | .054 | .061 | .069 | .076 | .092 | .107 | .122 | .142 | .179 | .215 |
| C | .041 | .048 | .054 | .061 | .067 | .080 | .094 | .107 | .124 | .156 | .186 |
| E | .154 | .178 | .202 | .227 | .250 | .298 | .346 | .395 | .458 | .574 | .689 |
| F | .065 | .073 | .081 | .089 | .097 | .113 | .130 | .146 | .168 | .207 | .247 |
| G | .132 | .153 | .175 | .198 | .217 | .260 | .303 | .344 | .402 | .505 | .606 |
| H | .050 | .058 | .066 | .075 | .083 | .093 | .115 | .132 | .153 | .193 | .232 |
| I | .023 | .027 | .030 | .033 | .037 | .043 | .049 | .056 | .064 | .080 | .096 |

## TABLE VIII

## AMERICAN STANDARD SET SCREWS
(THREADS ARE COARSE SERIES OR FINE SERIES)

TABLE VIII

American Standard Set Screws
(Threads Are Coarse Series or Fine Series)



| Diameter D | Width across flats W | Height of head H | Diameter D | Width across flats W | Height of head H | Diameter D | Width across flats W | Height of head H |
|---|---|---|---|---|---|---|---|---|
| 1/4 | 1/4 | 3/16 | 9/16 | 9/16 | 27/64 | 1 | 1 | 3/4 |
| 5/16 | 5/16 | 15/64 | 5/8 | 5/8 | 15/32 | 1 1/8 | 1 1/8 | 27/32 |
| 3/8 | 3/8 | 9/32 | 3/4 | 3/4 | 9/16 | 1 1/4 | 1 1/4 | 15/16 |
| 7/16 | 7/16 | 21/64 | 7/8 | 7/8 | 21/32 | 1 1/2 | 1 1/2 | 1 1/8 |
| 1/2 | 1/2 | 3/8 | | | | | | |

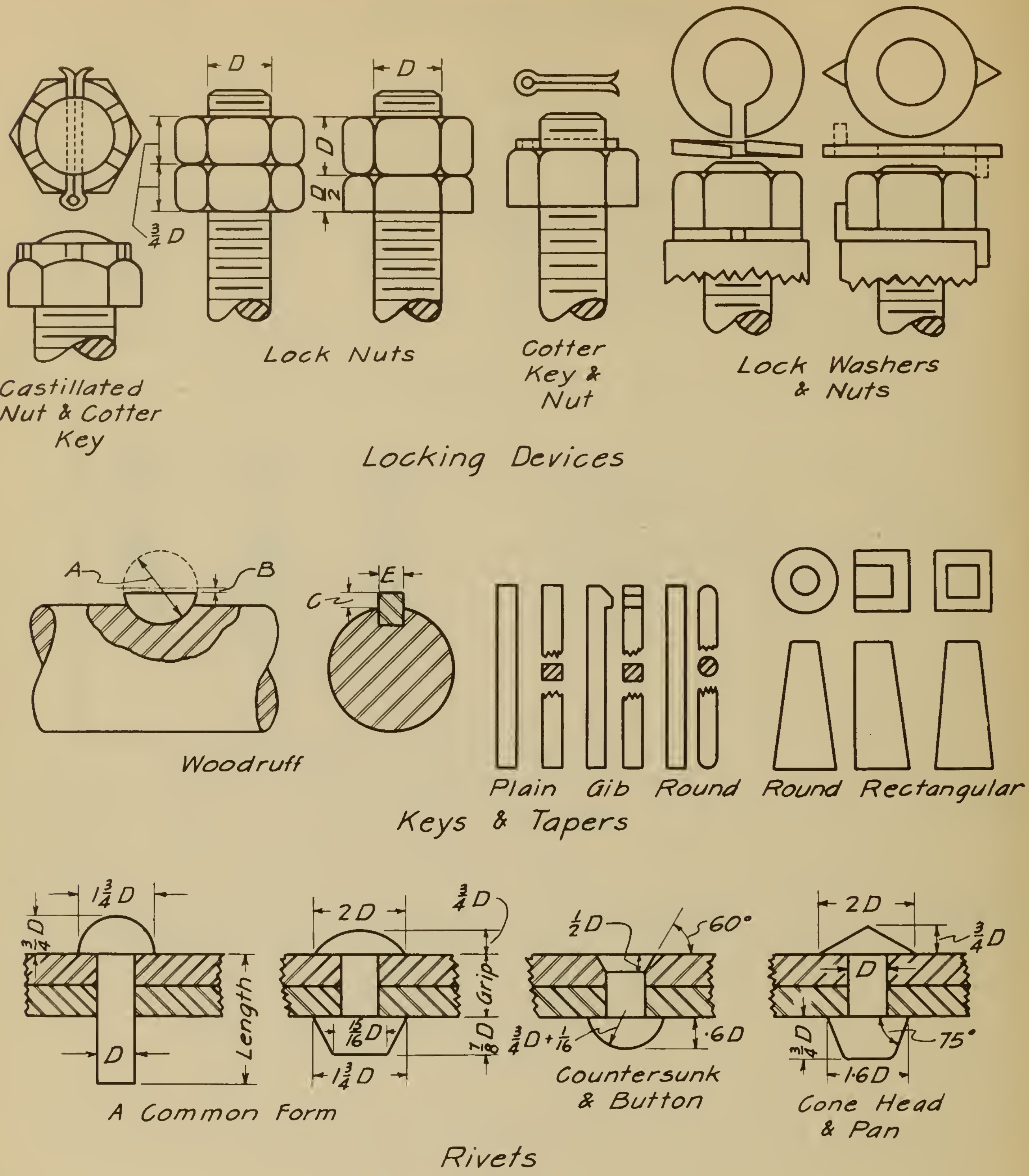


Figure 4-A. Miscellaneous Fasteners

## TABLE IX

### WIRE AND SHEET-METAL GAGES
(DIMENSIONS IN DECIMAL PARTS OF AN INCH)

| Number of gage | 1 American or Brown & Sharpe | 2 Washburn & Moen or American Steel & Wire Co. | 3 Twist drill sizes | 4 U. S. Std. for plate |
|---|---|---|---|---|
| 0000000 | ..... | .4900 | ..... | .5000 |
| 000000 | .5800 | .4615 | ..... | .4688 |
| 00000 | .5165 | .4305 | ..... | .4375 |
| 0000 | .4600 | .3938 | ..... | .4063 |
| 000 | .4096 | .3625 | ..... | .3750 |
| 00 | .3648 | .3310 | ..... | .3438 |
| 0 | .3249 | .3065 | ..... | .3125 |
| 1 | .2893 | .2830 | .2280 | .2813 |
| 2 | .2576 | .2625 | .2210 | .2656 |
| 3 | .2294 | .2437 | .2130 | .2500 |
| 4 | .2043 | .2253 | .2090 | .2344 |
| 5 | .1819 | .2070 | .2055 | .2188 |
| 6 | .1620 | .1920 | .2040 | .2031 |
| 7 | .1443 | .1770 | .2010 | .1875 |
| 8 | .1285 | .1620 | .1990 | .1719 |
| 9 | .1144 | .1483 | .1960 | .1563 |
| 10 | .1019 | .1350 | .1935 | .1406 |
| 11 | .0907 | .1205 | .1910 | .1250 |
| 12 | .0808 | .1055 | .1890 | .1094 |
| 13 | .0720 | .0915 | .1850 | .0938 |
| 14 | .0641 | .0800 | .1820 | .0781 |
| 15 | .0571 | .0720 | .1800 | .0703 |
| 16 | .0508 | .0625 | .1770 | .0625 |
| 17 | .0453 | .0540 | .1730 | .0563 |
| 18 | .0403 | .0475 | .1695 | .0500 |
| 19 | .0359 | .0410 | .1660 | .0438 |
| 20 | .0320 | .0348 | .1610 | .0375 |
| 21 | .0285 | .0317 | .1590 | .0344 |
| 22 | .0253 | .0286 | .1570 | .0313 |
| 23 | .0226 | .0258 | .1540 | .0281 |
| 24 | .0201 | .0230 | .1520 | .0250 |
| 25 | .0179 | .0204 | .1495 | .0219 |
| 26 | .0159 | .0181 | .1470 | .0188 |
| 27 | .0142 | .0173 | .1440 | .0172 |
| 28 | .0126 | .0162 | .1405 | .0156 |
| 29 | .0113 | .0150 | .1360 | .0141 |
| 30 | .0100 | .0140 | .1285 | .0125 |
| 31 | .0089 | .0132 | .1200 | .0109 |
| 32 | .0080 | .0128 | .1160 | .0102 |
| 33 | .0071 | .0118 | .1130 | .0094 |
| 34 | .0063 | .0104 | .1110 | .0086 |
| 35 | .0056 | .0095 | .1100 | .0078 |
| 36 | .0050 | .0090 | .1065 | .0070 |
| 37 | .0045 | .0085 | .1040 | .0066 |
| 38 | .0040 | .0080 | .1015 | .0063 |
| 39 | .0035 | .0075 | .0995 | ..... |
| 40 | .0031 | .0070 | .0980 | ..... |

1. Recognized standard in U. S. for wire and sheet metal of copper and other metals except steel and iron.
2. Recognized standard for steel and iron wire. Called the U. S. Steel Wire Gage.
3. Known as the "Manufacturers' Standard."
4. Legalized U. S. Standard for iron and steel plate, although plate is now always specified by its thickness in decimals of an inch.

## TABLE X

## DECIMAL EQUIVALENTS OF FRACTIONS OF AN INCH

| | | | |
|---|---|---|---|
| 1/64 = .015625 | 17/64 = .265625 | 33/64 = .515625 | 49/64 = .765625 |
| 1/32 = .03125 | 9/32 = .28125 | 17/32 = .53125 | 25/32 = .78125 |
| 3/64 = .046875 | 19/64 = .296875 | 35/64 = .546875 | 51/64 = .796875 |
| 1/16 = .0625 | 5/16 = .3125 | 9/16 = .5625 | 13/16 = .8125 |
| 5/64 = .078125 | 21/64 = .328125 | 37/64 = .578125 | 53/64 = .828125 |
| 3/32 = .09375 | 11/32 = .34375 | 19/32 = .59375 | 27/32 = .84375 |
| 7/64 = .109375 | 23/64 = .359375 | 39/64 = .609375 | 55/64 = .859375 |
| 1/8 = .125 | 3/8 = .375 | 5/8 = .625 | 7/8 = .875 |
| 9/64 = .140625 | 25/64 = .390625 | 41/64 = .640625 | 57/64 = .890625 |
| 5/32 = .15625 | 13/32 = .40625 | 21/32 = .65625 | 29/32 = .90625 |
| 11/64 = .171875 | 27/64 = .421875 | 43/64 = .671875 | 59/64 = .921875 |
| 3/16 = .1875 | 7/16 = .4375 | 11/16 = .6875 | 15/16 = .9375 |
| 13/64 = .203125 | 29/64 = .453125 | 45/64 = .703125 | 61/64 = .953125 |
| 7/32 = .21875 | 15/32 = .46875 | 23/32 = .71875 | 31/32 = .96875 |
| 15/64 = .234375 | 31/64 = .484375 | 47/64 = .734375 | 63/64 = .984375 |
| 1/4 = .25 | 1/2 = .5 | 3/4 = .75 | 1 = 1.0 |

## TABLE XI

## METRIC CONVERSIONS

| Mm. to In. | | | | In. to Mm. | | | |
|---|---|---|---|---|---|---|---|
| Mm. | In. | Mm. | In. | In. | Mm. | In. | Mm. |
| 1 | .0394 | 17 | .6693 | 1/32 | .79 | 17/32 | 13.49 |
| 2 | .0787 | 18 | .7087 | 1/16 | 1.58 | 9/16 | 14.28 |
| 3 | .1181 | 19 | .7480 | 3/32 | 2.38 | 19/32 | 15.08 |
| 4 | .1575 | 20 | .7874 | 1/8 | 3.17 | 5/8 | 15.87 |
| 5 | .1968 | 21 | .8268 | 5/32 | 3.96 | 21/32 | 16.66 |
| 6 | .2362 | 22 | .8661 | 3/16 | 4.76 | 11/16 | 17.46 |
| 7 | .2756 | 23 | .9055 | 7/32 | 5.55 | 23/32 | 18.25 |
| 8 | .3150 | 24 | .9449 | 1/4 | 6.34 | 3/4 | 19.04 |
| 9 | .3543 | 25 | .9843 | 9/32 | 7.14 | 25/32 | 19.84 |
| 10 | .3937 | 26 | 1.0236 | 5/16 | 7.93 | 13/16 | 20.63 |
| 11 | .4331 | 27 | 1.0630 | 11/32 | 8.73 | 27/32 | 21.43 |
| 12 | .4724 | 28 | 1.1024 | 3/8 | 9.52 | 7/8 | 22.22 |
| 13 | .5118 | 29 | 1.1417 | 13/32 | 10.31 | 29/32 | 23.01 |
| 14 | .5512 | 30 | 1.1811 | 7/16 | 11.11 | 15/16 | 23.81 |
| 15 | .5906 | 31 | 1.2205 | 15/32 | 11.90 | 31/32 | 24.60 |
| 16 | .6299 | 32 | 1.2598 | 1/2 | 12.69 | 1 | 25.39 |

4
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